

# The Water Balance of the Alps

What do we need to protect the water resources of the Alps?

Proceedings of the Conference held at Innsbruck University, 28-29 September 2006

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# Foreword

Roland Psenner<sup>1,2</sup> and Reinhard Lackner<sup>1</sup>

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There is little doubt among scientists, administrators and law persons that water will be a crucial issue for the future of the Alps – independently of the particular climate change scenario that will become true. The articles in this issue of the *innsbruck university press* present a wide range of expert opinions on these matters, from law to limnology, which all show that the importance of water – be it scarcity, floods, or quality – goes beyond the Alpine range and will affect millions of people in Europe. The simple consideration that the Alps could provide 40% of the water used in the European Union, tells us that the definition of the Alps as “Water towers of Europe” (Schwaiger, p. 3) is no exaggeration. Describing the role of the Alps as the principal water resource, defining problems, challenges and opposing views – these were the main objectives of this meeting, organized by the University of Innsbruck on behalf of the Ministry of Agriculture, Forestry and Environment.

Intensive discussions about the best way to protect sensitive water bodies in the Alps – either by implementing specific and hitherto neglected aspects peculiar to mountain regions into the EU Water Framework Directive or by creating a new Water Protocol for the Alpine Convention – went along with the presentation of fresh views on known water problems. As Borsdorf and Scheurer (p. 7) point out, water is a central topic in the research agenda of the International Scientific Commission on Alpine Research (ISCAR) as well as for the Alpine Convention, and a likely cause of potential conflicts between tourism, environmental protection, transport and energy production.

Before tackling such issues, however, one has to ask the basic question “who owns the water” (Weber, p. 13), or who has the right to use water? Questions of ownership or allowance of use may help us to consider this issue without fearing that EU laws could force countries with rich water resources to deliver it to the have-nots, although a free and globalised market can overcome national borders. While the Austrian law focusses on the allowance of use but accepts private ownership of water resources, the Swiss law regards glaciers as objects which have no owners. Bütler (p. 19), therefore, suggests to extend the protection of glaciers, which are not even mentioned in the EU Framework Directive on Water Policies, by adoption of a new Water Protocol of the Alpine Convention. The role

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of (melting) glaciers is highlighted by Braun and coauthors (p. 33) who present the mass balance of Vernagtletscher during the last 32 years – definitely a story of losses, i.e. about 300 mm per year on average.

Kajfež-Bogataj (p. 43) discusses the potential response of the Alps to climate change, a complex issue because of the fact that the Alps are at the crossroads of four different climate regimes and large enough to create their own regional climatic conditions. The Alps have experienced a warming of 2°C in the 20<sup>th</sup> century and the pronounced warming is expected to continue throughout the 21<sup>st</sup> century, leading to a complex pattern of effects, such as weather extremes, flooding and droughts. Nickus (p. 53) shows that global change is more than just warming and that alpine lakes can undergo a number of changes, from shifts in ice cover and stratification to metal pollution. She argues that environmental protection or restoration will become a difficult task since we have to consider – beside a number of stressors – also a shifting baseline. Maiolini and Bruno (p. 67) revisit the famous River Continuum Concept from an “Alpine” viewpoint, showing that disruption and the loss of connectivity is possibly the greatest problem for rivers in the Alps, but potentially also in lowland streams. Most river systems affected by hydropower generation (hydropeaking) must be considered as heavily modified water bodies. There is, thus, urgent need to restore alpine rivers.

The aim of the conference was to present the view of researchers as well as of administrators, and to discuss the best way to protect sensitive waters, including ice and snow, of the Alps. A follow-up conference, scheduled for 2008 in Germany, is expected to define legal and administrative measures to achieve this goal.



# Alps – the Water Towers of Europe

Karl Schwaiger

Lebensministerium, Austrian Presidency of the Alpine Convention

The Alps are often called the “water towers” of Europe. Looking at Europe as a whole, we have to note, that considerable parts of Europe were confronted with severe water shortages and water scarcity endangering severely social and economic development in the last years. The mitigation of negative impacts due to droughts and water scarcity has therefore become an important political issue at national level as well as at the level of the European Union. Regions concerned are not only the countries south of the Mediterranean Sea like Libya or Egypt or similar countries. No, those long term imbalances in the water availability are also spotted in the southern parts of Portugal, Spain, France, Italy and Greece and – but this is not so widely known - also for example parts of United Kingdom south east of London.

In sharp contrast to this critical situation the Alps provide enormous quantities of water to large parts of Europe via e.g. the rivers Danube, Rhine, Po, Rhone. Please let me allow you to describe you the situation in the Danube basin to illustrate the importance of alpine water contributions to other regions: The Danube has a catchments area of roughly 810.000 square kilometres. In spite of Austria’s share of just about 10 percent of this area one out of four water drops entering the Black Sea via the Danube comes from Austria, and here in particular from our alpine regions. Just to repeat, 10 % of the catchments area of the Danube contributes close to 25 % of the overall discharge of the Danube into the Black Sea. Thus, the Alps provide not only enormous quantities of water but also water of excellent quality. Examples for this are the excellent drinking water quality in the city of Innsbruck or Vienna and in many other cities of the Alpine region, where spring water can be directly used for drinking water purposes without any prior removal of pollutants.

## *Competing interests in the Alpine Area*

But allow me now to abandon the resource side and to look at the challenges. The Alpine region is an area extremely sensitive and vulnerable to all sorts of impacts including global change. According to a documentation provided by the permanent secretariat of the Alpine Convention – the Alpine region is covering 191 000 square kilometres and home to about 14 million inhabitants. This results in a rather modest density of population of just above 70

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inhabitants per square kilometre. But if we take account of the fact, that those 14 million inhabitants are not at all evenly distributed but mostly concentrated in the narrow valleys and basins within the alpine region, and then we get population densities very similar to the one we observe in urban areas.

Adding to this impact, all the transit routes with their traffic, all the industry and the economic drivers are also concentrating on these rather limited areas. These areas are therefore characterised by a strong competition of conflicting interests. These conflicting interests arise also from the legitimate wish of residents to allow for a sustainable social economic development on one hand and the urgent need to protect our rather endangered resources in nature and water for future generations to the utmost extent on the other hand. But we have also to take note of the fact, that if one is living in the alpine area endangered by floods and avalanches he is expecting protection against those natural hazards; living in a landscape of extreme beauty, we cannot ignore the wish to profit from this opportunity by fostering tourism; if the residents of the region are not in favour of consuming nuclear energy nor want to contribute to climate change, generation of hydroelectricity is an important issue and there are other examples for conflicting interests. Looking at this potential competition of interests we have to find a sound balance among the different expectations and that is why we are here at this conference.

### *New legal instruments – a value per se?*

The question is now whether we are in an urgent need for new legal tool to provide a balance between different expectations or whether we can build on the already existing comprehensive set of legal instruments to protect the ample water resources of this our region for future generations. Please allow me to underline, that a separate new legislative tool may not be seen as a value per se. Therefore an in depth assessment is necessary to find out whether there are any important regulatory gaps left for an efficient protection of our Alpine water resources. To assess this properly, we have to analyse in more detail what we already have as results out from on going research, what are the important water management issues to be tackled with as well as what we already have as legislative frame.

### *Legislative Frame*

One important legal instrument really tailor made to the alpine region is the alpine convention, which entered into force step by step and country per country until 2000. This legal instrument provides a frame for so far 8 separate protocols addressing issues such as traffic, energy, spatial planning, nature protection, mountain forests. Other protocols foreseen by the Convention are for issues such as air, waste, culture, population and last but not least water. A first draft of a separate water protocol was circulated 2003.

Without going into any details I want to highlight 2 developments which have taken place since the Alpine Convention has been negotiated in the early 90ies and which may play a crucial part, when we assess the potential need of a separate new legal instrument.

- firstly a number of water legislation has been implemented within the European Union since the early 90ies such as the EU – Water framework directive, the EU Nitrates directive addressing diffuse pollution, the EU Urban Wastewater Directive addressing urban point sources, the Drinking water Directive, the forthcoming EU – Directive on the assessment and management of flood risks as well as the EU – Groundwater Directive and
- secondly, we have to acknowledge, that the eastern borders of the European Union have moved far to the east, so that Community Legislation is now applied in almost all alpine countries with one exception; that exception is Switzerland, which has an adequate separate national legislation and is closely cooperating with EU member states in the field of water based on the UN - ECE Convention of transboundary waters and lakes and its catchments approach.

Looking at this developments one might come to the conclusion, that the future focus should be less on a new instrument and more on an environmental sound implementation of the existing set of water legislation and in particular of the EU Water Framework Directive, where a river basin management plan has to be finalised together with a program of measures by end 2009.

I am pretty sure, that we will hear more about the existing legal frame as well as about potential needs for protection resulting from ongoing research.

*Outlook and way forward*

The outcome of the conference “The water Balance of the Alps“ is expected to provide policy makers and institutions with a list of themes that must be dealt with if we want to guarantee a sustainable use of the alpine water resources for future generations (and here we are extremely grateful to the research side presenting their results) and last but not least to provide clarification with regard to a potential need of separate Water protocol. The Austrian water administration is here rather open minded. In principle we see 3 potential options:

- first option is that we might see an urgent need for a separate new legal instrument, under the assumption that significant regulatory gaps will be traced in the Conference preventing us to protect our water resources efficiently for future generation
- second option, that there is no need at all for a separate legal instrument , under the assumption, that all aspects and needs for protecting our waters for future generations are already covered by existing provisions
- third option is, that the Conference might reveal themes, gaps, uncertainties, which might make a further follow up worthwhile.

# A Research Agenda Proposed to the Alpine Convention: Perspectives of the International Scientific Committee on Research in the Alps (ISCAR)

Axel Borsdorf  
Austrian Academy of Sciences

Thomas Scheurer  
Swiss Academies of Sciences

ISCAR – the International Scientific Committee on Alpine Research started as an inter-academic initiative of the Swiss Academies of Science and was officially founded in 1999 by the Austrian Academy of Sciences, an Italian partner – today the National Mountain Institute (IMONT), the Bavarian Academy of Sciences, the Slovenian Academy of Sciences and Arts and a French partner, today represented by the University and Research Pole Grenoble (see Fig. 1).

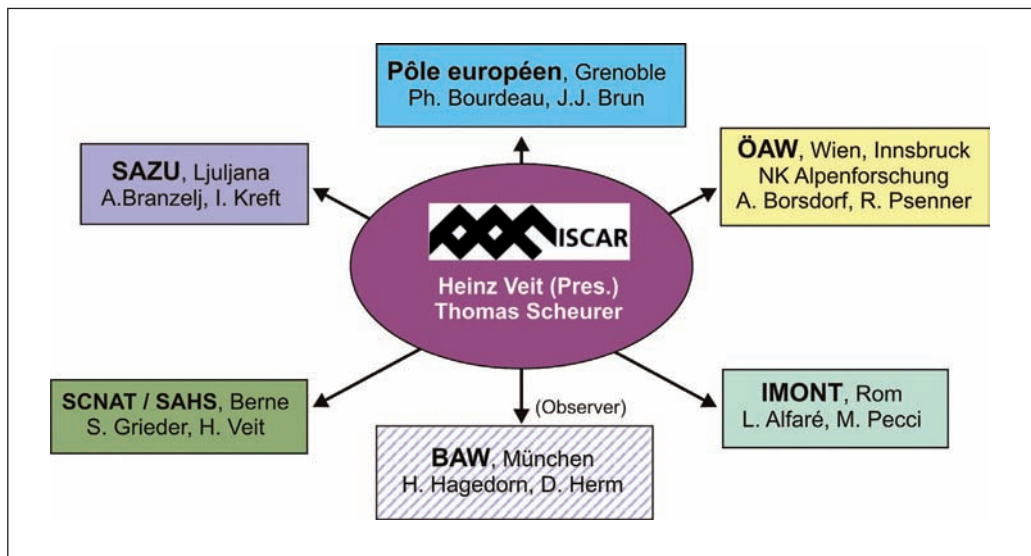


Fig. 1: Structure of ISCAR, International Scientific Committee on Research in the Alps 2006.  
(design: A. Borsdorf)

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The national partners send two delegates each to ISCAR. The ISCAR office is located at Berne, its president is Professor Dr. Heinz Veit, its Executive Secretary Dr. Thomas Scheurer. From the beginning ISCAR was appointed an official observer to the Alpine Convention.

When in November 2004, under the German presidency, the Alpine Conference approved the Multi-Annual Work Programme (MAP) 2005-2010 of the Alpine Convention, ISCAR, as an official observer of the Alpine Convention, initiated a reflexion on the MAP with the motif to propose scientific research topics related to the Multi Annual Work Programme. Throughout two workshops and two consultations, about 50 scientists from all alpine countries discussed the main objectives of the MAP from a scientific point of view and finally proposed a Research Agenda for the Alpine Convention.

It is the objective of this paper to link the Multi Annual Work Programme (MAP) of the Alpine Convention with the research agenda of ISCAR, to demonstrate which topics may be of high importance for alpine research related to MAP, and to highlight the water topic within MAP and ISCAR's research agenda.

The Multi-Annual Work Programme highlights four “Key Issues”. These are 1st “mobility, accessibility, transit and traffic”, 2nd “society, culture, identity”, 3rd “tourism, leisure, sports” and 4th “nature, agriculture and forestry, cultural landscape”. The Alpine Convention expected that the collaboration of different players and experts in the alpine space will initiate important synergy effects and will create progress in the sense of the Alpine Convention. As the Alpine Convention also invited all interested actors to participate in the active realisation of MAP, ISCAR, the leading network of scientists in the area of alpine research, felt a high responsibility for the scientific aspects and the elaboration of a research agenda, related to the MAP.

For each of the four key issues of MAP the following research fields were formulated by ISCAR:

### **Key issue 1: Mobility, Accessibility, Transit, Traffic (Chap. 2.1. MAP)**

- 1a. Development of mobility patterns over time
- 1b. Regional and urban development in the context of accessibility
- 1c. Impacts of traffic and related infrastructures: evaluation and monitoring
- 1d. Steering of transport: instruments and their impacts

**Key issue 2: Society, culture, identity (Chap. 2.2. MAP)**

- 2a. Individual well-being
- 2b. Social cohesion – social dynamics – cultural identities
- 2c. Regulation in territorial transformation and management
- 2d. Multi-level capacity in actor-networks

**Key issue 3: Tourism, leisure, sports (Chap. 2.3. MAP)**

- 3a. Evaluation of competitiveness of existing and new touristic models in the context of globalization
- 3b. Relationships between culture and tourism in touristic areas
- 3c. Interactions between urbanisation and alpine tourism
- 3d. Sustainable management of winter stations
- 3e. Governance and co-operation in alpine tourism: developing policy-based and agent-based approaches (How to organize tourism within and among touristic areas?)
- 3f. Potentials and strategies of sustainable nature-based tourism and sports in the Alps
- 3g. Touristic transport infrastructures in high mountain areas

**Key Issue 4A: Land use, spatial planning, protection (Chap. 2.4. MAP)**

- 4a. Influence of management strategies and cultivation methods on landscape functions and ecosystem services
- 4b. Influence of land use changes on biodiversity (genetic, species, habitat, landscape)
- 4c. Interactions between social life-styles, land use changes and landscape structures
- 4d. New approaches to identify, develop and and monitor ecological connectivity areas

**Key Issue 4B: Global change, natural risks, resource management**

- 4e. Regional Climate change in the Alps: prediction and scenarios
- 4f. Global Change effects on vulnerability and natural risks in Alpine regions
- 4g. Governance and management of water resources in changing water cycles

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With the formulation of this research agenda, ISCAR's job is not completely done. In the near future for each topic will be outlined: a rationale, the research goals, actions, and the identification of the main stakeholders. Furthermore, ISCAR will designate for each key issue a research institute for the main responsibility to promote and co-ordinate research and actions.

The Research Agenda is intending mainly transalpine and interdisciplinary research and is therefore complementary to existing research. Finally, the Research Agenda is aiming to be a reference a) for developing future research or cooperation programmes concerning alpine space, b) for national or European agencies funding alpine research, and c) for scientists developing new transdisciplinary research projects in alpine-wide dimension. Whenever possible, the proposed topics of the Research Agenda should be integrated in future inter- or multinational and interdisciplinary research programmes, such as EU-FP 7, Interreg IVb: Alpine Space and CADSES, COST, the Global Land Project, or programmes implementing the Research Strategy on Global Change in Mountain Regions (GLOCHAMORE). The research agenda is also intended to serve as a reference for research project applications and an evaluation scheme for peers, reviewing proposals or results. The results from such research activities should provide a substantial support to achieve goals of the multi-annual working programme until 2010. The complete proposed Research Agenda to the multi-annual working programme of the Alpine Convention will be published in early 2007.

In Key Issue 4B.g of the research agenda the water topic is formulated under the title "governance and management of water resources in changing water cycles". This may be realised on two levels, an analytical one and an applied one. Basic research should therefore concentrate to the analysis of changes of water cycles, including an exact description and the discussion of causes, conditions, consequences, prognoses, and – if possible – recommendations for solutions for a sustainable development. This includes the thematic field of Global Change with different aspects like climate change, economic, political and cultural globalisation, changes in consumption behaviour and more.

The second level is much more orientated to applied research, especially under the aspects of administration and/or governance. It includes therefore the search for best practices and solutions in management, administration, budgeting, and – under governance aspects the steering on multi levels, the adaptation of legal regulations and more (Fig. 2).



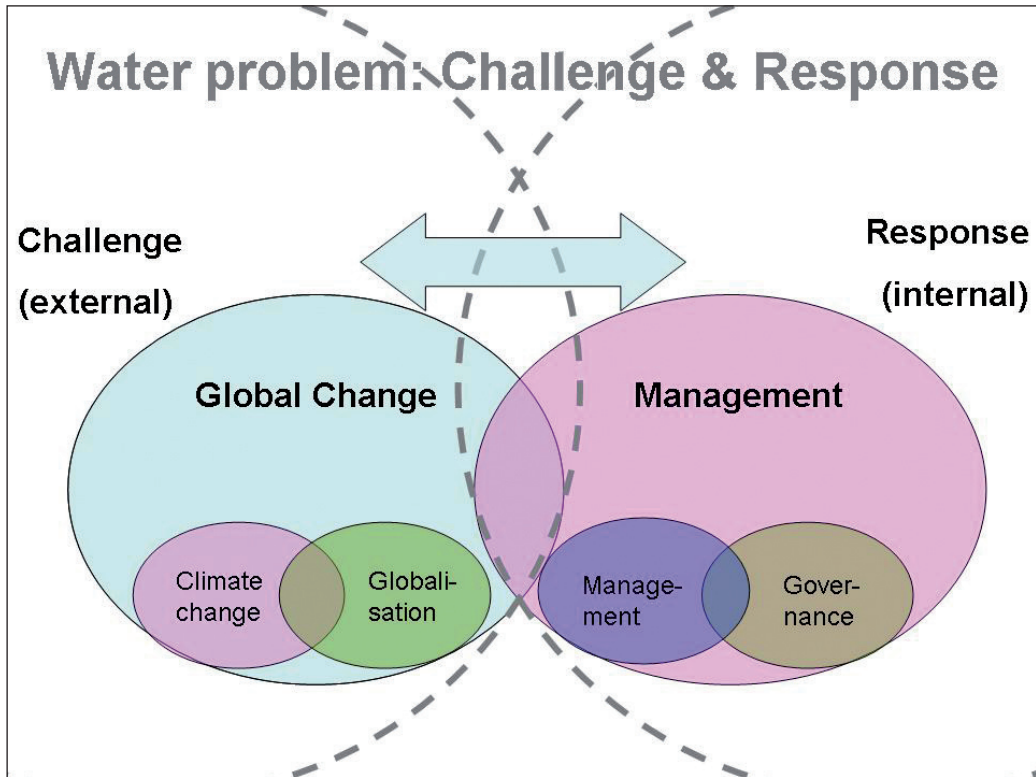


Fig. 2: The water question – challenge and response (design: A. Borsdorf)

However, it must be mentioned, that ISCAR’s research agenda neither intends to restrict research in any way, nor to have the water issue exclusively investigated under the aspects, formulated in the chapter 4Bg. Therefore also other topics of the research agenda have strong relationships to the water issue, like „regional climate change in the Alps: prediction and scenarios“ or „global change effects on vulnerability and natural risks in Alpine regions“. Research proposals related to these topics therefore may also include central questions like relationship to water cycles, water deposits, water quality or to natural risks by inundations and droughts.

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# Who Owns the Water?

Karl Weber,

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I. The question “Who owns the water?” may sound easy to the juridical layperson, it is however quite a complex question that very often follows winding juridical paths. I assume that the majority of the people present today are non-jurists; therefore I would like to try and answer this question in a way that is also comprehensible for non-jurists. For those lawyers who work professionally on the law of waters my remarks will not bring many new insights. I do, however, believe that at an event such as this one also the legal aspects or at least their basics should be presented. This is what I would like to do in this short presentation.

II. The right to utilise water – that is what the question who owns the water actually is about – is one of the oldest legal institutions in the world. Already in ancient Egypt and Mesopotamia the utilisation of water was regulated by law. In the Roman Law there was a highly developed law of waters. It was based on the principle of common usage, thus equal access to the common property water was legally secured. The prohibition to alter the natural watercourse was already an enforceable claim in ancient times (*actio aquae fluviae arvene*).

Also in the Teutonic Law water utilisation was an important topic. While the Roman Law was based on the common usage, in the Teutonic Law the co-operative principle was prevalent. Those who were bordering on a watercourse formed a co-operative which took the advantages and also had to care for the works of maintenance. In the Teutonic Law only the navigable rivers and streams were common property, the other waters were very well subject to individual property. They were, however, very often *Allmende*, which means that they were open to be used by the other persons of the legal entity, usually the community. The “*Teildinge*”, Teutonic courts of the lower instance, issued regulations and orders which characterized the law of waters until way up to the modern times and some features can even be found in today’s law of waters.

The economic development of the early and late modern age was characterised by the rise of trade and early industrial method of production, which increasingly pushed the use of water power (mills, saw-mills, hammer mills and others). From the 16th century on there were imperial mill-rules which regulated water utilisation. Already at that time the utilisation of water was subject to official approval; we also find rules that take into account existing

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water rights and rules on administrative powers of supervision. With the emergence of the modern state since the era of Maria Theresia, the law of waters and in particular the right to utilise water were more and more refined. For the first time the ABGB from 1811 contained written rules on the character of water as a subject to property law. This was the starting point for the discussion on whether water can be subject to civil law acquisition of property. Parallel to this civil-law regulation of the water utilisation also in public law numerous rules on the law of waters emerged. These rules of public law subordinated the private water utilisation to public interest and developed a system that makes almost all the rights to dispose of water subject to administrative approval and this is still prevalent in today's WRG.

III. The ABGB declares streams, rivers, seaports and seashores as general or common property (§ 287 ABGB). Common property are goods that are dedicated to common use. Also the WRG distinguishes between public and private waters.

The qualification as common property does, of course, not mean that it cannot be owned by a person – more specific a juristic person, usually a territorial entity (Bund, Länder, communities). Common use only means that the common property can – according to certain rules – be used by everyone under the same conditions and without official approval; it can also be used independently from and even against the will of the owner. Therefore public waters are at the disposal of civil law. Every territorial entity can agree upon a water utilisation that goes beyond common use by a civil law legal act with a third party.

IV. The regulations on the disposal of water are not based on the term water (H<sub>2</sub>O) but on the term waters which is more comprehensive than the term water. Waters covers the water on the surface, ground water, water beds as well as watersides. This shows that the term waters is more comprehensive than the mere term water. Also dried riverbeds are e.g. subject to the law of waters, even when the dry up is not only periodical.

V. When we now turn towards the actual question of who owns the water, we first of all have to assume that all the waters have an owner. The most important public waters are owned by the Bund, private waters are normally owned by the owner of the land through which the water flows or on which the lake, spring, pond lies. The ownership powers of the Bund are partly exercised by the Landeshauptleute (governors of the land) (on behalf of the Bund), the Austrian Bundesforste (lakes) and the Wasserstraßendirektion (Danube, March, Thaja).

VI. The answer to the question who the owner of waters is does not yet answer the question who owns the water as the usage of the water does not so much depend on the civil-law legal title but much more on the public law right to utilise. The public law rules on the use of water overlap the civil law aspects because the public law of waters is the right to utilise waters and therefore also water, independent from who the owner is.

At the beginning I have already mentioned that the common use has characterized the development of the law of waters since ancient times. Also in today's WRG common use is a general principle and is systematic at the beginning of the law. The common use refers to public and private waters. According to § 5 subsection 1 WRG the utilisation of public waters is – within the legal limits – open to everyone. The common use of public waters is the equal and ordinary use of water without special device and does not exclude others from the use of water. As examples the law names bathing, washing, watering, sweeping, scooping, the extraction of plants, mud, gravel and others. The common use must, however, neither endanger the watercourse or the quality of the water or the watersides nor affect public interest or infringe the rights of others.

Today this form of common use of public waters is only of minor importance. Most likely the bathing in lakes that are public waters can be considered. All the other forms of use are hardly of any importance today because the extraction of gravel and shingle is only allowed without special devices which means only with buckets and baskets. The similar extraction of mud or aquatic plants is also no longer of importance. Every use that goes beyond this common use requires an official approval.

The common use of private waters is restricted to watering and scooping with small vessels. The owner of the land is, however, permitted to close the access to his private waters (e.g. with a fence) and therefore to make this “minor” common use more difficult or even impossible.

The owner of private waters can only practise his water right without the approval of the water-authorities in so far as foreign rights, the fall, the quality of the water or the water-level are not affected. Likewise also the utilisation of waters that endangers the waterside or that bears the danger of flooding foreign property or turning it marshy require official approval.

The WRG therefore makes it clear that without official approval the powers of the owner are quite restricted. The same holds true for public waters. This means that in the end it is the water-authority that bestows the water rights. In short one could also say that water and waters have private and public owners, to use them, however, a special right under public law is required. That is why in a way the water “belongs” to the water-authorities. The administrative approvals, which I will refer to in detail later, are subjective public rights that

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cannot be transferred by acts of civil law. Although two private persons can agree on the utilisation of water by a civil law contract, they need an official approval by the authority to set the terms of the contract into force. From this follows that the private autonomy in the field of the law of waters is very much restricted in favour of administrative approval under public law.

As an interim result we can state that all the waters are owned by natural or juridical persons, public waters in particular are owned by the Bund or another territorial entity. The access of these owners to their water that is not subject to approval is, however, restricted. As soon as subjective rights of a third person are affected, the course of the water, the security concerning flooding, the quality of the ecological function of the water and many more are affected also the exercising of the owner's rights requires a special official approval. In a very subordinate sense we all own water because we all are entitled to common usage.

VII. I have already mentioned that the rules on the utilisation of water focus on the public interest. Therefore the legislator rules that those measures that go beyond common use or affect interests in the area of the law of waters, are subject to official approval. It is incumbent upon the authority to assess the extent of the danger and future impairment in an administrative procedure and to draw the legal conclusions. § 105 WRG expounds a large enumeration of protected interests which can lead to a denial of the approval. In all these cases of petitions for water utilisation – this can be the extraction of water for industrial purposes or for the construction of a river- or storage power station, the setting up of a drinking water system, the construction of flood protection works or the activities concerning building and settling near waters – it is always the authority that has to secure public interests such as the water quality, the ecological functioning, the protection of water reserves for the local supply and other interests. If it is to be feared that the project affects public interests, the authority can, however, only refuse the approval if also by means of conditions these interests cannot be met; furthermore the impairment of these interests must be more serious than the benefit for the public interest. Of course, also economic interests are public interests, as can be seen from the judicature on the use of water by the textile or paper industry, the energy industry and others.

VIII. In principle water belongs to the owner, the rights of the owner are very much regulated by law and in the end it is the authority that decides upon the extent, intensity and duration of the water utilisation according to the WRG and other legal norms. It can, however, also happen that the water suddenly belongs to someone who originally was neither owner nor in any other way authorised to utilisation. Under the heading “coercive rights”

the WRG provides possibilities of expropriation. Therefore according to the WRG also a person who is not owner of waters can submit a project of water utilisation. If this project is officially approved, the competent authority (the Landeshauptmann, governor of the land) can dispose the expropriation. Expropriations are possible, they must however remain a measure of ultima ratio. The rules of expropriation usually lead to intense negotiations between the owner and the petitioners because they have to prove that they tried everything possible to acquire the property, water-right etc voluntarily, which is by means of civil law. Usually they are also ready to pay much more than the estimated value because the procedures of expropriation are lengthy and quite often can delay a project for years. Again and again there are persistent landowners or persons authorized to use the water who do not want to give away their property voluntarily.

In the law of expropriation always the mildest measure has to be taken. Therefore the expropriation does not necessarily lead to a complete taking away, it is also possible to impose compulsory – even temporary – grants of a right.

IX. We have seen that property can belong to all of us (common use), that it can belong to individual people authorized to use and owners. We have also seen that most powers of ownership referring to water and waters are subject to approval and the use is under official supervision. Finally we have now got to turn to the question who owns the water from the international point of view. The topic water-sale is repeatedly in the centre of political discussions and even in election debates. Whilst inland the water utilisation is regulated by national law, questions concerning the cross-border water utilisation is regulated by international law and European law. In the international law there are in principle three restrictions of the national water utilisation as far as it affects other states:

- Equitable utilisation – as far as conjunct waters are concerned, every border state has the right to an adequate and reasonable part of the possible utilisation.
- Equitable appointment – utilisation and impairments of conjunct waters should preferably be ruled in a contractual agreement on the basis of a free weighing of interests and shall lead to a adequate compensation for possible impairments and restrictions.
- Priority of the drinking-water supply – utilisation of water must never endanger the drinking-water supply in one of the border states. In view of the imminent disputes over water, especially in the near and middle East, in Africa but also in other continents, in the future the international law will play an important role in the maintenance of national interests concerning the law of waters.

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As far as the dreaded sell-out of the water in the Alps is concerned, one can say that due to the existing European legal situation there is no real danger for the national water-resources in the Alps. Although the common water-policy does allow the development of a water-policy of the EU, a compulsory regulation to that effect that the Alpine states are obliged to deliver their water resources to arid areas (e.g. Spain), does not yet exist. Also the current water-framework directive does allow a coherent system of management, it does, however, not contain obligations. Therefore the danger that is again and again depicted does not so much come from the Communitarian law but much more from the free market economy and globalisation. As water is a good that can be subject to ownership, it is of course also subject to the free movement of goods in the European Union and the general rules of a free and globalised market economy. However, most national laws on water in the Alps make sure that water is only then delivered abroad when neither the supply of the regional and national population is endangered, nor negative consequences for the water balance, the quality and ecological functioning of waters nor other national interests exist. Therefore from today's point of view, a sale of water is quite possible, a sell out, however, is not to be expected in the near future.

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# Glaciers – Objects of Law and International Treaties

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## *Introduction*

### **Legal aspects concerning Swiss glaciers**

In terms of natural science glaciers are characterised by the formation of ice masses from snow accumulation, mass balance, ice movement and transport of debris<sup>1</sup>. In the Swiss Civil Code glaciers are classified as objects which have no owner, as soil unsuitable for cultivation and as public property in common use. Public glaciers are ruled by the law of the canton in which they are situated. The cantons can have the territorial sovereignty or claim public or private property on glacier areas or delegate such rights to their communities. If there is sufficient evidence, glaciers can, as an exception, be of private ownership. Even in such cases mountaineers have the right of free access without motorized vehicles as long as they do not cause any damage. Famous examples are the Rhone glacier and the Aare glaciers. The family Seiler, whose members were tourist pioneers, erected a hotel near ice caves in the Rhone glacier and so attracted a huge number of foreign tourists. Due to those activities and in correspondence with old cantonal law the Seilers occupied the Rhone glacier according to a decision of the Federal Supreme Court in the year 1936. Today it is not possible anymore to acquire the property of a glacier area in such a way according to the law in force<sup>2</sup>.

When the authorities survey the alpine zones for the land register they have to draw the line between soil suitable for cultivation on one hand and rock and glacier areas on the other. Some of the owners of alpine pastures do not agree with this drawing up of borders, especially if they have old written sale contracts with differing descriptions of borders. Until the beginning of the 20th century most of the mountain peaks did not have names and the plots were not yet described in a land register nor with square meters. In earlier centuries it was common to describe the borders of alpine pastures with neighbours, cardinal points or mountain peaks. A typical example could be the formulation «the pasture x stretches towards evening (the northern direction) to the snow summit».

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1 For an overview see Bütler, pp. 7-19, with references to specific literature

2 Bütler, pp. 21-57, especially pp. 36-41.

## The Water Balance of the Alps

The interpretation of centuries-old sale contracts for pastures, especially the description of borders, often is a central but difficult point. A disputed opinion of one expert suggests that before the year 1800 nobody had any interest in glaciated areas. This school of thought was applied by courts in some famous cases and led to a very restricting interpretation of such formulations. As a consequence the proof of private property in glacier regions with old documents can be very difficult<sup>3</sup>. Today it is practically impossible to get an approval of the competent authorities to acquire new private property of such soil. Nowadays building and other activities are often based on legal instruments like the right to build, the permission for increased common use, a concession or lease instead of private property or servitudes which have no time limitation. This makes a lot of sense: glaciers should be in public hands – for public interests and ecological reasons – and not become objects of commercial dealings.

In the last thirty years, many disputes between cantons, municipalities and/or private persons about property in glacier areas have been brought to Swiss courts. The reasons for this can be found in increased economical, social and ecological activities in high alpine regions. Priority is on tourism and energy production. Another famous example besides the above mentioned Rhone glacier case is the conflict between the two coexisting communities of Zermatt (Burger- and Munizipalgemeinde) during nearly thirty years. They fought for property in the skiing area Theodul-Klein Matterhorn and all surrounding mountains and glaciers (Matterhorn inclusive)<sup>4</sup>.

Cantonal and municipal authorities, the responsible persons, clubs and companies for roads, mountain paths, cable cars or ski-regions have to take precautionary measures against glacier hazards like ice avalanches and glacier lake outbursts; rockfall because of glacier retreat and melting permafrost also have to be mentioned here. Crevasses pose a threat to Alpinists and users of glacier ski runs. Depending on the constellation legal duties to maintain safety are based on public or private law. For the authorities the relevant laws are in the fields of police, protection of the population, area planning, forest, water and environment as well as private law for the liability of owners of buildings. Private persons, alpine clubs and companies have the duty to take care of their activities in glacier regions as owners of buildings and other infrastructures or as contractual partners. Examples are transport contracts of cable car companies with their passengers or the mandate of a mountain guide with his guest. For the building up of glacier slopes a special directive aims at reducing the dangers for the users<sup>5</sup>.

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3 Bütler, pp. 138-146.

4 Details about cases of property conflicts in the Swiss Alps: Bütler, pp. 93-138

5 Details in Bütler, pp. 149-221.

Catastrophes and accidents related to the mentioned glacier phenomena have caused many deaths and often have been followed by legal proceedings. Famous is the catastrophe of Mattmark (canton Wallis) in August 1965, when the tongue of the Allalin glacier suddenly broke off and fell directly on a building site which caused the immediate death of 88 workers. After a long legal procedure all accused were acquitted<sup>6</sup>. For alpinists on glacier tours priority is on the question about when and how to use the rope. The basic rule, confirmed by the jurisdiction, is to rope up if the planned route of a team leads through glacier passages that are partly or fully covered by snow; combined with a good routefinding and rope handling technique the risk of a sudden crevasse fall can be substantially reduced<sup>7</sup>.

### Glaciers – objects of international treaties

The most important international treaties to protect glaciers are the Antarctic Treaty System, the UN Framework Convention on Climate Change and its Kyoto-Protocol. Antarctica is the continent of ice and glaciers; only two percent of its surface are ice-free. It is encircled by floating barriers of ice. The Antarctic Treaty was signed in the year 1959 by twelve states in order to establish a peaceful scientific cooperation and to set aside territorial claims by any party. All military activities have been prohibited from then on. In the meantime many agreements followed; they form the so called Antarctic Treaty System<sup>8</sup>.

The Protocol on Environmental Protection to the Antarctic Treaty, which was agreed in the year 1991, deserves special mentioning. It aims at a comprehensive protection of the Antarctic environment and its ecosystems; its wilderness, aesthetic values and the conduct of research are especially emphasized. Activities in the Antarctic area should avoid any adverse impact on climate or weather patterns or significant changes in the glacial environment (Art. 3). The exploitation of mineral resources is prohibited. Waste disposal is strictly regulated: prohibited in ice-free areas and limited as much as possible for sea ice, ice shelves and the grounded ice sheet. Examples for major glacial ecosystems, outstanding geological and glaciological features can be part of specially protected areas (Art. 3 of Annex V)<sup>9</sup>.

The fluctuations of glaciers and climate change are closely connected. The ongoing climate warming is an existential threat for the alpine glaciers in temperate zones. The Arctic ice shelf and – in the medium term – the inland ice of Greenland are endangered too; their substantial melting could have huge and irreversible effects on ocean currents, sea level and

6 Bütler, pp. 154-155 and 253-262.

7 See Bütler, pp. 223-252 (alpine duties) and 263-288 (judgments on cases with glacier accidents).

8 See [http://www.antarctica.ac.uk/About\\_Antarctica/Treaty/index.html](http://www.antarctica.ac.uk/About_Antarctica/Treaty/index.html); Sands, pp. 710-713.

9 Sands, pp. 721-726.

## The Water Balance of the Alps

on global climate<sup>10</sup>. In order to undertake steps against a rapid climate change caused by human activities, the UN established a regime to reduce the amount of released greenhouse gases. The UN Framework Convention on Climate Change of the year 1992 and its famous Kyoto Protocol of 1997 are the legal basis<sup>11</sup>. The ultimate objective of the convention is to stabilize the greenhouse gas concentrations of the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Glaciers, sea ice, ice shelves and ice sheets are not mentioned directly but they are a key factor in the discussion on the effects of climate warming. This is because of their role as an indicator for climate change, their value as water resource and attractive landscape factor and their influence on climate, oceanic circulation and on the sea level.

In the Kyoto Protocol industrialized countries commit themselves to reduce their overall anthropogenic emissions of carbon dioxide by at least five percent below the 1990 levels in the commitment period between the years 2008 and 2012. The parties are obliged to fulfil their emission reductions mainly with domestic actions; but flexible instruments can be employed in a supplementary way to allow efficient and cheap measures abroad. These instruments are the so-called Joint Fulfilment, Joint Implementation, Clean Development Mechanisms and International Emissions Trading<sup>12</sup>. There is widespread consensus among scientists that the current climate protection measures are completely insufficient. Furthermore, no international legal regime has been defined until now for the period after the year 2012. The total of global anthropogenic greenhouse gas emissions should be reduced by about three thirds compared to the 1990 levels in the next few decades. Not even such drastic steps can give a guarantee to slow the ongoing climate warming process effectively and in time<sup>13</sup>.

### *Protection of the glaciers in the Alps*

#### **Endangering of glacier regions through human activities**

Since the 19th century the Alps have been increasingly conquered and developed for tourism and for industrial purposes. Already in the beginning of alpine tourism the then

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10 Overview about glaciers and climate in: Bütler, pp. 411-441; detailed retreat-scenarios for Swiss glaciers in: Maisch Max/Wipf Andreas/Denneler Bernhard/Battaglia Julius/Benz Christoph, Die Gletscher der Schweizer Alpen, Gletscherhochstand 1850, Aktuelle Vergletscherung, Gletscherschwundsenarien, 2. Aufl. Zürich 2000, pp. 273-320.

11 See <http://unfccc.int>.

12 For an overview about international climate law: Sands, pp. 357-381; Bütler, pp. 443-469.

13 See for example ProClim, p. 88; World Meteorological Organization, p. 216; Bütler, pp. 432-433.

much bigger glaciers were one of the main attractions for foreign visitors, poets and painters. In the period between 1850 and 1920, when refrigerators did not yet exist, ice exploitation was performed to a great extent on many Swiss glaciers. Huge ice lumps were transported to several major cities of Switzerland, France and Italy. Beginning of the 20<sup>th</sup> century famous mountain railways leading to glaciated areas such as Jungfrauoch or Gornergrat (Switzerland) were constructed. After World War II, the booming skisport and mass tourism were accompanied by the construction of cable cars, ski lifts, ski slopes, restaurants, roads and other infrastructure, in several cases in high alpine glacier areas. Of current interest are glacier coverings, snow farming and artificial snow production<sup>14</sup>.

The rising consumption of electricity in the last century required the construction of huge water reservoirs. In the Swiss Alps a large part of the glacier water is abstracted and collected in mains and huge dams. This entire infrastructure has severely disfigured and changed the sensitive high alpine landscapes<sup>15</sup>. Also activities and events like pop concerts, theatre-performances, rides with snowmobiles and ski races (Rettenbachferner/Austria) take place on certain glaciers. On the Klein Matterhorn near Zermatt (Switzerland), which measures 3883 meters above sea level, a second cable car, a restaurant with 400 places, a tower with the height of 117 meters and an observation platform as well as a hotel with artificial overpressure are planned<sup>16</sup>. Efforts have to be made that this absurd and megalomaniac project will be refused.

Other negative effects are caused by alpine air traffic and military shooting exercises. Supply flights for alpine huts and for rescue purposes are widely accepted and appreciated. More problematic are fun flights and heliskiing which lead to a lot of noise, disturb animals and devalue alpine routes in the open country for mountaineers and skiers. Presently Switzerland has 43 official mountain landing places, about half of them in glacier zones up to an altitude of 4100 meters. In neighbouring countries like France, Germany, Liechtenstein, Austria or Italy, heliskiing is either forbidden or more restricted by law. Art. 12 of the Protocol «Traffic» of the Alpine Convention demands from the parties to try hard to limit or prohibit landings of aircrafts outside of airfields or airports. Switzerland has several alpine ranges with shooting sectors aiming at glacier regions. Tons of used ammunition lie scattered on certain glaciers, even in protected areas; examples are the Fiescher and the Aare glaciers in the cantons of Wallis and Bern. Since some years now, the army has begun – as a reaction to criticism – to collect some of the used ammunition, but the problem of pollution with heavy metals is by far not yet solved<sup>17</sup>.

14 Bütler, pp. 294-297 (endangering of glacier regions), 311-319 (snow farming, snow production and glacier covering); Elsasser/Bürki, pp. 16-23.

15 Bütler, pp. 367-371.

16 See the publicity under: <http://www.zermatt.ch/d/latest/Projekt-Klein-Matterhorn.html>.

17 For more details about military exercises and alpine air traffic see Bütler, pp. 371-379.

## Legal protection of glaciers in Switzerland

In Switzerland huge glacier regions are situated within protected areas which have been defined either by the federal state, by the cantons or communities. Basically the protection of landscapes is the duty of the cantons, an outflow of the still strong federalism in Switzerland<sup>18</sup>. Since the year 2001 the high alpine region Jungfrau-Aletsch-Bietschhorn (cantons of Wallis and Bern), including Aletsch glacier, is on the list of the Unesco World Heritage. Many beautiful alpine landscapes are listed in the so called Inventory of Landscapes of National Importance. While fulfilling its tasks, the federal state has the obligation to preserve such areas in an undiminished way; existing activities and minor interferences with the protection objects are tolerated. Unfortunately the description of the objects and the goals of protection are not precise enough. The cantons must take this inventory into account, but still have too much latitude in the handling. One problem is that a lot of activities in the touristic, energetic and military sector already existed when the inventory came into force. Nevertheless, one can say that the inventory has had a positive effect when new cable cars, water dams and other constructions were planned in protected areas. Several glacier forefields are protected in the Inventory of Meadows of National Importance<sup>19</sup>.

Switzerland has thirteen glacier ski-regions and many other railways leading to high alpine terrain. The construction of cable cars for skiing areas requires a concession and a planning permission based on an environmental impact assessment. In 1998 the Swiss government confessed to the principle of a reserved concession policy concerning especially high alpine regions. In protected areas no new permissions should be given.

Art. 7 of the decree about concessions for mountain railways and cable cars is important. This provision says that glaciers can only be developed with cable cars if they lie near major tourist villages. Furthermore, glaciers have to be particularly suitable for prolongation of the skiing season and for summer skiing. In several cases this provision was handled in a reasonable way. But in the newest case, Hockenhorn, it was totally misinterpreted in a decision made by the Swiss government in the year 2000. Below the Hockenhorn-peak a cable car leading over the small Milibach glacier was permitted although the village Wiler in the Lötschental Valley cannot be assessed as a «greater tourist center». The authorities argued that combined with another village, called Kandersteg, which is connected to Wiler only by a tunnel the requirements would be met. The government ignored the existing regulations in a legally unacceptable way for economic interests of local tourism in a valley with emigration-problems. Would this decision become standard, practically any Swiss glacier

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18 Bütler, pp. 323-328.

19 Bütler, pp. 328-339 (inventories of national importance), 351-353 (Unesco World Heritage).

could be developed with new cable cars. But the Swiss government admitted that it was a borderline case without prejudice for similar projects.

In Switzerland a new law and a decree about cable cars are being discussed and will come into force in the near future. The law states that the construction of cable cars can only be permitted if they are technically safe and environmentally compatible. Unfortunately, ecological standards, especially for the development of glacier areas, are lacking completely in the draft until now. For final decisions about concessions for cable cars competence will lie with the Federal Supreme Court, no longer with the Swiss government, which is quite an improvement. Nevertheless, glacier protection in Switzerland is not strong enough and not really satisfying<sup>20</sup>.

In several federal states of Austria which has eight glacier skiing areas the strict protection of glacier regions is regulated more explicitly. Examples are the states of Vorarlberg, Kärnten and Salzburg. In Tirol legal protection of glaciers has been weakened by the last revision<sup>21</sup>.

## **EU Framework Directive on Water Policy**

The EU Framework Directive on Water Policy is applicable in the whole area of the EU, but not in alpine countries like Switzerland and Liechtenstein, which are not members of the EU. For the water pollution control and for sea water protection it is a useful and necessary instrument<sup>22</sup>. Although the Directive includes the alpine regions of EU countries (see Art. 1 and Annex VI, Map A), it does not take into account the special geographical and hydrological circumstances of the Alps. This becomes obvious by the fact that snow, firn, glaciers and permafrost are not mentioned; neither are alpine water systems as a landscape factor (minimal rest water amounts) nor activities like artificial snow production, snow farming and glacier covering. In the Directive no regulations concerning preventive and reactive measures against alpine hazards like glacier lake outbursts, snow, ice and debris avalanches and rockfall can be found. Floods are mentioned in the Directive, but only in connection with the standards of water pollution control. At least alpine EU-States have the possibility to point out special alpine problems within the scope of their reporting duties according to the Directive (see Art. 15).

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20 Details about cable cars in Swiss glacier regions, Bütler, pp. 354-367; case «Hockenhorn»: pp. 400-410.

21 Hasslacher, pp. 7-14; see also Bütler, pp. 379-381.

22 Short summary about the Directive in: Sands, pp. 769-771.

## The Water Balance of the Alps

The European Commission has made a draft for a new Flood Directive which is based on the Directive on Water Policy and responds to the rising flood risk to people, property and environment with a cross-border approach. The Flood Directive would oblige the EU Countries to make flood risk management plans and to establish flood risk maps. In the draft mountainous flash floods which are especially destructive when combined with land-or mudslides are mentioned. But other alpine hazards like snow and ice avalanches or rock-fall due to melting permafrost are not included in the drafted Flood Directive<sup>23</sup>.

### Alpine Convention and its Protocols

The Alpine Convention, agreed in the year 1991, «was the first international legal instrument to address the environmental issues of mountain regions.»<sup>24</sup> In the Alpine Convention and its Protocols snow, glaciers and permafrost are not mentioned either. But the Protocol «Soil Conservation» deals with development for tourist and energetic purposes, water systems and alpine hazards. It urges the parties to draw cadasters of past events and maps showing the danger zones for debris and snow avalanches as well as floods. In the Protocol «Energy» the protection of alpine river basins against destruction for the purpose of water power is regulated. The Protocol «Conservation of Nature and Countryside» aims at the protection of mountain landscapes. In its preamble it states that glaciers, lakes and rivers have outstanding importance for the Alps as a living space for a diversified fauna and flora. Art. 14 paragraph 2 of the Protocol «Tourism» gives the parties the possibility to permit the artificial production of snow during local cold periods, especially to secure exposed zones, if the hydrological, climatic and ecological conditions allow it.

To a certain degree the aims of the above mentioned Protocols overlap with the drafted Water Protocol, but water, snow and ice are clearly not in the foreground. Because of the existential and central role of water there is an evident legitimation for a Water Protocol. Nevertheless, in my opinion the different fields could have been regulated in a shorter and more efficient way rather than in the various existing Protocols of the Alpine Convention. There is a slight tendency for overregulation.

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23 <http://ec.europa.eu/environment/water/>.

24 Sands, p. 535; for the text of the Convention and its Protocols see: <http://www.conventionalpine.org>; short overview in: Bütler, pp. 347-351.



## Glaciers in the drafted Water Protocol

On the occasion of the UNO-Year of Water in 2003 the International Commission for the Protection of the Alps (CIPRA) proposed a Water Protocol to amend the Alpine Convention<sup>25</sup>. In the preamble of the drafted Water Protocol, the role of the Alps as the «water towers» of Europe is stated as well as the concern about the effects of climate change. Art. 1 and 3 emphasize that the protocol includes water in all its physical conditions and names snow, ice, firn, glaciers and permafrost explicitly. Art. 7 obliges the parties to collect information about glaciers and to store and publish it in a common database. In the field of area planning the parties are required to show the hydrological danger zones and the erosion-endangered areas in their plans. Development has to be prohibited in zones that are put at risk by high waters and floods which can also be caused by glacier incidents. Art. 13 obliges the parties to undertake adequate measures of prevention to reduce the risks of high waters.

Art. 11 paragraph 4 is the core provision for glaciers, in the German version it says: «Die Vertragsparteien verpflichten sich, den Schutz der Gletscher zu gewährleisten und jegliche Nutzung von Gletschern zu untersagen, welche zur Beeinträchtigung der Gletscher oder zu ihrer Veränderung beiträgt. Sie erlauben keine weiteren Erschliessungen von Gletschern mit Infrastrukturen zu touristischen Zwecken.» This regulation would oblige the parties to ensure the protection of their glaciers and to avoid any use that could have a negative or changing effect on them. No new development with cable cars and other infrastructure for tourist purposes could be permitted in glaciated areas. Art. 11 is under the title «protected areas», this provision obviously is intended to provide best possible protection for all glaciers; but some points have to be discussed:

The text demands that no use of glaciers should be tolerated that could interfere with or change them. But it is clear that in already developed glacier ski-regions some interference with and change of glacier surfaces are inevitable for the proper preparation of the slopes or ice caves. The cable car companies have to fulfil security and legal obligations which need to be carefully distinguished from always remaining personal responsibility of each passenger. The companies have to protect their guests on prepared, secured and marked slopes from great or hidden alpine dangers like crevasses, snow and ice avalanches or rockfall.

The increasingly used techniques of snow farming, partial glacier covering with fleeces and artificial snow production for maintenance of ski-runs deserve particular attention.

25 German version of the Water Protocol: [http://www.cipra.org/d/alpenkonvention/offizielle\\_texte/Protokollvorschlag\\_d\\_Wasser.pdf](http://www.cipra.org/d/alpenkonvention/offizielle_texte/Protokollvorschlag_d_Wasser.pdf); until now no official English translation of the drafted Water Protocol exists. Information about CIPRA: <http://www.cipra.org>. Arguments for the need of the drafted Water Protocol are listed in: Sohnle, pp. 1-3.

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Snow farming means that huge amounts of snow are collected, transported and spread on slopes with vehicles. In my opinion snow farming should be allowed only to a limited extent and requires a planning permission. The same goes for the booming partial glacier coverings which are quite effective in protecting selected ice zones from solar radiation and excessive melting. White covering fleeces should be allowed only on problematic spots or artificial constructions (half pipes, snow parks) on glacier ski runs with a maximal surface of 20 000 m<sup>2</sup> per skiing area.

Partial glacier covering seems to be an ecologically better alternative compared to architectural measures, snow farming or snow production, which are usually combined. But it disturbs the alpine landscape during the summer months and might – depending on the quality of the fleece – impede the free access to glaciers. Glacier coverings are just a measure in the battle against the symptoms, not against the cause; they can not stop climate change. Covering fleeces should not be allowed on entire ski runs or on glaciers which are not yet exploited for the commercial skisport or which lie in protected zones. Glacier coverings should not be accepted as an ecological measure to shield our ice fields from melting.

In my opinion, snow production on glacier surfaces should be totally prohibited. This technique disturbs precious landscapes, especially delicate are ridges and exposed summit areas. It uses too much water and energy and causes a lot of noise; additives can have problematic effects on water, fauna and flora. Furthermore, it seems to be rather absurd to use this technique on glaciers which should be the most snow-secure regions in the Alps... Art. 14 paragraph 2 of the Protocol «Tourism» of the Alpine Convention addresses legislation for snow production and asks the parties to consider hydrological, climate-related and ecological conditions when they decide if problematic spots may be covered with artificial snow<sup>26</sup>.

On one hand Art. 11 makes clear that no further tourist infrastructure on glaciers can be allowed. In my interpretation this concerns not only so far unspoilt glaciers; it also includes glaciers besides existing skiing areas. This seems to me a little bit too strict. Renovations have to be permitted for security reasons and for renewals of concessions. Small enlargements of already existing skiing areas should not be totally excluded in view of the ongoing climate warming and the economical situation of the mountain regions. But the construction of new glacier slopes should only be allowed in exceptional cases and be restricted to small area chambers which are situated above existing winter sport areas and outside of protected zones.

The economic pressure, the competition between the mountain resorts and the high, sometimes inappropriate demands for comfort of the visitors should not be underestimated

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26 Bütler, pp. 311-319 about snow farming, snow production and glacier covering.

and disregarded. Otherwise mountain regions should receive some financial compensation for strict protection of all their glacier areas. But the tendency to «flee» to higher and higher areas for winter sport purposes in times of hard competition and climate warming should clearly be restricted. It does not make sense to develop any more vanishing glaciers by building cable cars and other installations in a hectic and unreflected way. The scars would stay there for a long time - with or without glaciers.

On the other hand the text of Art. 11 does not mention new infrastructures for energetic, telecommunicative or military purposes which can also interfere heavily with landscape and soil protection. In my understanding, such installations are not ruled out clearly enough by the Water Protocol. This omission remains somewhat in disbalance with the stern attitude towards touristic infrastructures and might lead to misinterpretation. About ten years ago a new gigantic water dam called «Grimsel West» was planned in the Berner Oberland in the Swiss Alps. The filled lake would have buried the tongue of Unteraar glacier at a length of about three kilometers. Fortunately this project failed for economical reasons. Instead, a reduced enlargement project is now under way which would overflow the (protected!) forefield of the Unteraar glacier. It has to be admitted, though, that energy from water power is renewable and makes a lot of sense; in Switzerland a huge part of the glacier water is abstracted and used for energy production, so this infrastructure already exists in a great number. The biggest threat for glacier regions clearly derives from climate change and tourist development plans.

Equally, heliskiing and other air traffic, rides with snowmobiles as well as military shooting exercises are not mentioned in the Water Protocol; but those activities can be subsumed under the formula of «use with a negative effect». Air traffic and snowmobiles cause noise and air pollution; such activities seem to be unjustified in view of their considerable emissions for the benefit of very few persons only and taking into account the numerous existing cable cars. Also very problematic is the used ammunition waste on glaciers which will eventually pollute melting water and the subjacent soil with heavy metals.

Priority should be given to the complete abstention from building up new infrastructures in big unspoilt and/or already protected glacier areas; exceptions should be allowed for security measures on instable mountain paths and for the renovation of alpine huts. In existing winter sport areas renovations or small enlargements can be permitted based on founded reasons if the environmental impacts are moderate.

### *Conclusion and proposal*

The Water Protocol emphasizes the protection of glaciers in the Alps from new tourist infrastructures. In my opinion, this focus is a little too strict whereas other points such as infrastructures for energetic and military reasons and air traffic are omitted in the regulation. Therefore I propose to slightly modify Art. 11 paragraph 4 as follows:

«Die Parteien verpflichten sich, den Schutz der Gletscher zu gewährleisten und jegliche Nutzung von Gletschern zu untersagen, welche zu ihrer Beeinträchtigung oder Veränderung beiträgt. Sie erlauben keine neuen Erschliessungen von Gletschern mit Infrastrukturen für touristische, energetische, militärische oder andere Zwecke. In erschlossenen Gletschergebieten sind Erneuerungen der Anlagen, eine umweltverträgliche Bewirtschaftung sowie in begründeten Ausnahmefällen ein eingeschränkter Ausbau innerhalb der genutzten Geländekammern zuzulassen.»

Glacier protection touches many fields which are interconnected in a partly very complex way. The climate system, noise and air pollution, interferences with landscape and water systems are to be mentioned. Current protection varies a lot in the alpine countries and is not satisfactory. Therefore the Water Protocol with its high regulation standard is recommendable<sup>27</sup>. The existing EU Framework Directive on Water Policy is not sufficient for glacier protection. To close part of this gap the Directive on Water Policy could be revised or the existing Protocols of the Alpine Convention could be amended. In my opinion, the adoption and ratification of a new Water Protocol by the alpine countries would be a good way to set a clear signal for the Protection of our precious alpine water resources and glaciers.

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<sup>27</sup> See also Sohnle, pp. 1-3.

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# Water Balance of the highly Glaciated Vernagt Basin, Ötztal Alps

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Annual glacier mass balances of the Vernagtferner have been determined by the Commission for Glaciology since 1964 using the direct glaciological method. Precipitation and other climatological variables, and also discharge have been measured since 1974 at the “Pegelstation Vernagtbach” gauging station. This high alpine basin has an area of 11.4 km<sup>2</sup>, extends from 2640 m to a maximum elevation of 3630 m, and the glacier area decreased from 9.7 km<sup>2</sup> (85%) in 1964 to 8.1 km<sup>2</sup> (71%) in 2006.

According to this analysis a mean annual precipitation sum of 1525 mm is determined. Mean discharge amounts to 1790 mm, a measured value that can only be maintained by a mean negative glacier mass balance of -305 mm with respect to the total basin area over the 32 years of records considered here. While the Vernagtferner winter balances have remained more or less stable at a value of 1000 mm over the past 40 years, the summer balances show an obvious trend from values of -1000 mm in balanced years when measurements began, towards strongly negative values in the 1990s, culminating in the year 2002/03 with a record summer balance of -3120 mm, and basin runoff amounting to 3380 mm. Basin evaporation is of minor importance, and was estimated as a constant value of 120 mm/y over the whole period. Further investigations are needed to get more confidence of its impact on the total water balance.

The drastic changes in runoff conditions demonstrate the impact of global change in this high alpine environment, and the monitoring efforts need to be continued on a long-term basis with high priority.

## *Introduction*

The Vernagtferner has been observed closely since the year 1600. From then on the glacier had advanced rapidly into the Rofen valley in intervals of about 80 years, causing the formation of an ice-dammed lake which burst out and drained rapidly with disastrous results. The first detailed map of Vernagtferner was drawn in 1889 by S. Finsterwalder, with an accuracy comparable to modern maps, and since then, glacier volume changes have been calculated, describing quantitatively the general retreat of this glacier since 1850 due to global warming. These results demonstrate the long history of scientific investigations of glacier behaviour and its relationship to climate conditions in the Ötztal Alps, Austria.

## The Water Balance of the Alps

Comprehensive long-term observations over decades are needed in order to detect evidence of climate change during the past and in the future. Due to the “long memory” of the processes involved, it is necessary to provide information over a period long enough to explain the current evolution of glaciers as a reaction to climate variation. For this reason it is important that data series are continuous and homogeneous, requirements which are not easy to fulfil. For the determination of the water balance components, for example, the challenge lies in the reliable evaluation of the areal precipitation, estimation of evaporation, direct measurement of glacier mass balance and the continuous recording of the glacier runoff.



*Fig 1: Pegelstation Vernagtbach situated at 2640 m a.s.l. with the climate measuring station on the left. (Photo taken September 30, 2003).*



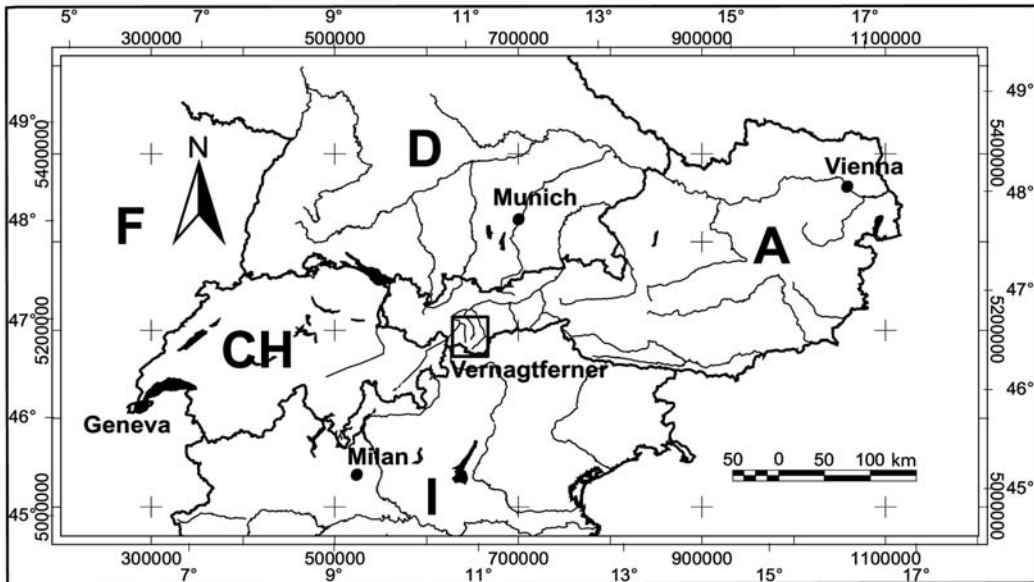


Fig. 2: Location of the Vernagtferner basin in the Alps.

For the last parameter mentioned, the “Pegelstation Vernagtbach” (Fig. 1) provides the means to obtain an accurate, long-term record of the total discharge of the Vernagtferner. This hydro-meteorological station is situated at 2640 m a.s.l. about 1.5 km downstream from the glacier terminus of the Vernagtferner in the Oetztal Alps (Austria). In Fig. 2, the position of the catchment in the Alps is indicated with a rectangle on the map showing the major neighbouring states of this alpine region. For the Vernagtferner basin (Fig. 3) hydro-meteorological data have been recorded since 1974 as part of the glacier monitoring programme of the Bavarian Academy of Sciences and Humanities. The data set comprises meteorological parameters i.e. radiation, air temperature, humidity, pressure and wind velocity, while runoff and precipitation are the major hydrological ones. Even earlier, direct measurements of annual glacier mass balances were initiated in 1964, resulting in a data set spanning four decades of total glacier mass balance. Thus, the three quantitatively most important terms of water balance have been available since 1973/74. Initial results were already published for the period 1973/74 to 1984/85 by Moser et al. (1986). The analysis presented here was obtained using similar methods and extended to the period 1973/74 to 2004/05. A more extended description of the methods applied are given in Escher-Vetter et al. (2005), where, additional information is provided on the winter and summer glacier mass balances, and updated figures of the water balance for the measurement period 1974 to 2005 are given.

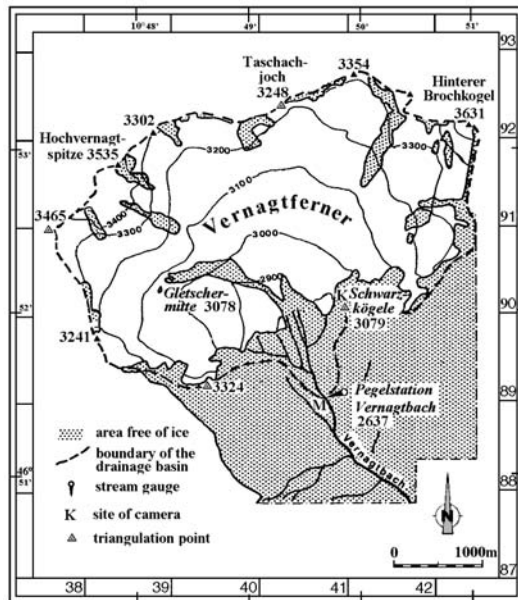


Fig. 3: The Vernagtferner basin with position of recording sites and location of ablation stakes and snow pits. Basin area is 11.4 km<sup>2</sup>.

### Precipitation

Traditionally, basin precipitation has been determined separately for the winter and summer seasons (Moser et al., 1986; Escher-Vetter et al., 2005). As practically all precipitation falls as snow in winter in this basin, the direct measure of the water equivalent (w.e.) of the snow pack on the glacier at the end of the month of April is a reliable and consistent estimate of winter precipitation on the glacier (see also chapter on glacier mass balance below). Up to 3050 m a.s.l. a general increase in the w.e. is observed with increasing elevation, above this limit the w.e. is more closely correlated with the distance from the watershed ridge in the NW to SE direction, which corresponds to the prevailing wind direction (Plattner et al., 2006). The snow cover in the pro-glacial area of Vernagtferner is highly variable from place to place due to the uneven ground surface and wind-induced redistribution of snow. Based on sporadic measurements, the w.e. of the snow cover in this non-glacierized part of the basin is estimated at 60% of the lower-most 50 m elevation band on the glacier.

The annual precipitation figures presented in this study are based on the application of the conceptual runoff model HBV3-ETH9 (Bergström, 1992; Braun and Renner, 1993; Braun et al., 2000; Ellenrieder et al., 2004). In this application, basin precipitation values (see Table 1 and Fig. 5) are derived from daily precipitation sums measured at the Vernagtbach gauging

station corrected with the multiplicative rain correction factor (RCF, optimal value = 1.60) and snow correction factor (SCF, value = 2.05), depending on the aggregational state of precipitation (optimized temperature threshold value  $T_0 = -0.5^{\circ}\text{C}$ ). The optimal correction values were obtained by taking into account both discharge and snow accumulation data. The mean annual precipitation values correspond quite well with the values derived from measured winter and summer precipitation (Escher et al., 2005, deviation less than 20 mm), but individual yearly values do in fact differ up to 500 mm in some years.

### *Glacier Mass Balance*

For Vernagtferner the data collection for the separate determination of winter and summer mass balances has been performed since the very start of the measurements in 1965. The data basis for the accumulation determination, however, varies to some degree. Whereas the total balance is based on roughly the same amount of ablation stakes (approx. 50), only a small number of snow pits were dug and density measurements performed in the early years, and in the worst case the winter mass balance analysis was based on only three pits and a handful of depth soundings. The data set improved in the eighties and nineties, and since 1999, five snow density profiles and between 100 and 330 snow depth soundings have provided a good coverage of the glacier area. A reanalysis of the whole data set was performed in 2006, which resulted in some corrections of earlier published data (Moser et al., 1986), and some data gaps could be closed (Escher-Vetter et al., 2005), so the whole series is determined with the same methodology, based on the measured altitudinal distribution of the winter snow cover (see Fig. 4).

Over the whole period, the summer balances show a clear trend from -1000 mm w.e. in the 1960s and 1970s to some -2000 mm w.e. in the 1980s and 1990s, culminating in more than -3100 mm w.e. in 2002/03. The total balance for this year amounted to -2130 mm w.e., while in the lowest part of the glacier the ice diminished by 5.8 m in depth. The correlation coefficient between summer and total mass balance for the whole series is 0.82, between winter and total mass balance 0.04, i.e. no correlation at all. That the summer mass balance basically determines the annual balance is also documented by the standard deviations of the time series: the standard deviation for the annual mass balances (501 mm water equivalent) is nearly the same as that for the summer balances (506 mm w.e.).

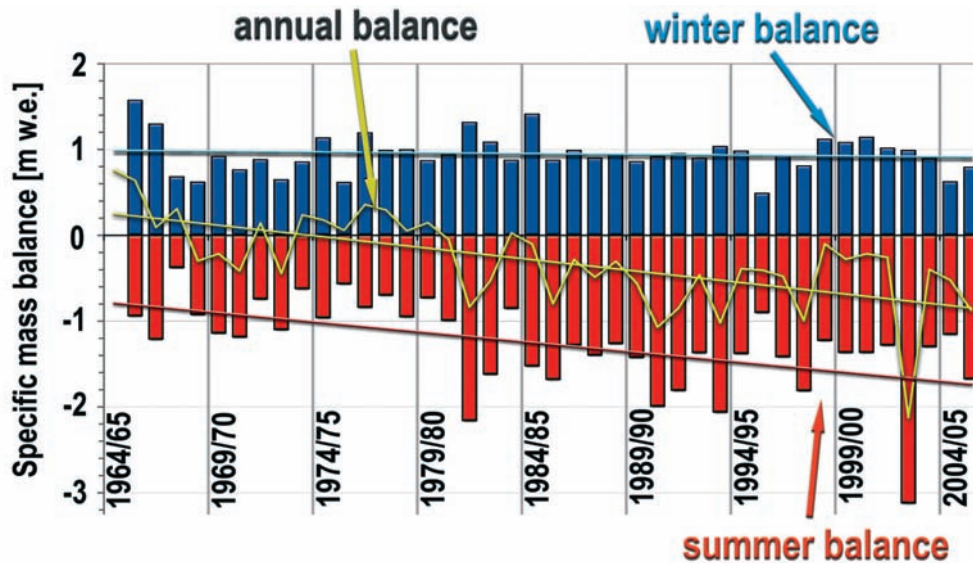


Figure 4: Winter, summer and annual mass balance of the Vernagtferner for the period 1964/65 to 2005/06. The trend lines indicate the evolution of the individual terms. Glacier area varies between 9.7 km<sup>2</sup> in 1964 and 8.1 km<sup>2</sup> in 2006.

### Runoff

As the Pegelstation Vernagtbach is positioned on a solid rock barrier, the recorded discharge comprises all the water drainage from the glacier. Several independent measuring and recording devices enable a near to uninterrupted discharge series on an hourly basis since 1974. The diurnal variations of discharge have increased over these thirty years due to strong glacier mass losses since 1980 and the thinning of the firn areas. In October 1995 and July 2000 the measurement channel of the gauging station had to be rebuilt to adapt the flow capacity to increased diurnal flood peaks. These structural adaptations were essential in order to protect the gauging station against flood damage (Reinwarth and Braun, 1998), in particular when strong melt was combined with intense rainfall. This was the case, for example, in the summers of 1987 and 1994, where the measurement channel was unable to capture total discharge. The estimated peak discharge was approximately 20 m<sup>3</sup>/s, whereas the highest recorded hourly value from meltwater alone amounted to 15 m<sup>3</sup>/s on August 5, 2003. These values are contrasted by winter runoff data with only some 10 l/s, which is typical for the glacial runoff regime. On the whole, the annual sums of discharge have approximately doubled within the thirty years of the station's operation (see Fig. 5).

Whereas no hourly average surpassed the amount of  $10 \text{ m}^3/\text{s}$  until 1992 (Escher-Vetter and Reinwarth, 1994), this limit was surpassed during 135 hours on 37 days in the summer of 2003. The annual amount of discharge volume of this exceptional year was 22% higher (3300 mm w.e.) than in the year 1993/94 (2600 mm w.e.), which until then was the year with the highest annual discharge.

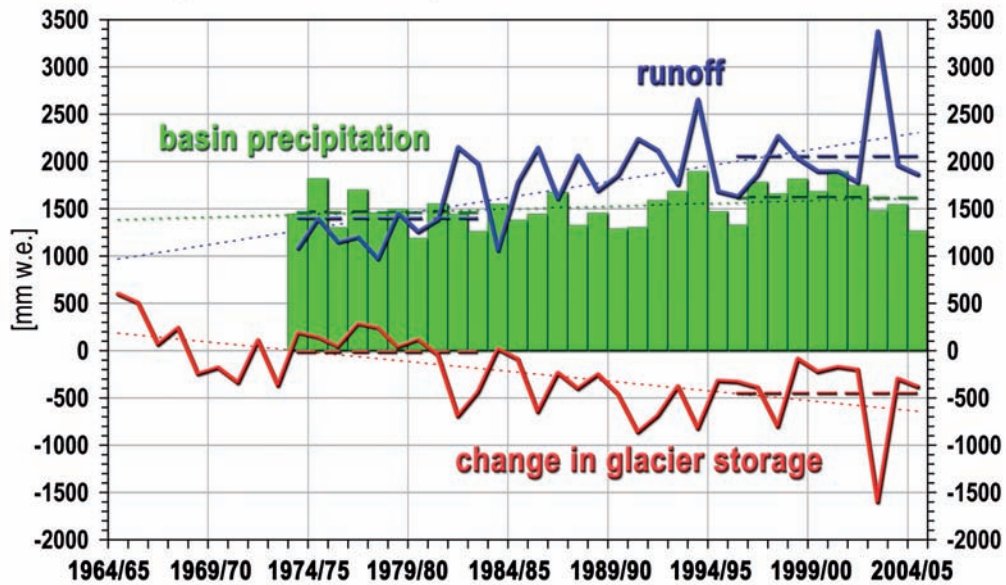


Fig. 5: Selected terms of the water balance of the Vernagtferner drainage basin as based on direct measurements.

### Evaporation

The amount of mass loss due to evaporation is generally small compared to the amount of precipitation and runoff in this high alpine environment. The catchment area can be subdivided into glacierized and non-glacierized parts. Over snow and ice surfaces condensation conditions are more frequent than evaporation conditions. With increasing height evaporation is further reduced, however, mass losses due to sublimation from turbulent suspension of wind-induced laterally transported snow increase remarkably. As a result net losses through evaporation and sublimation increase with height, but only over small area fractions (Strasser et al., 2007). In the water balance evaluation presented here an evaporation value of  $120 \text{ mm/a}$  is calculated for a  $1 \times 1 \text{ km}^2$  grid cell around the gauging station Vernagtbach for the years 1995 and 1996 in the framework of modelling land surface

## The Water Balance of the Alps

processes in the GLOWA-Danube project (<http://www.glowa-danube.de/frameset.htm>; Strasser et al., 2005; Weber and Kuhn, 2005). In a first approximation this value is taken as representative for the entire basin and for the total time period investigated here (see Table 1). In comparison to the evaporation sums which were determined as a residual of the water balance during the special research programme “Runoff in and from glaciers” for the period 1978 to 1985 (Moser et al., 1986) this estimation is smaller. The average over those 8 summers amounted to 157 mm with a range of 124 to 186 mm. Investigations on other glaciers resulted in evaporation values between 114 mm/a and 221 mm/a (Braun et al., 1994). Further modelling efforts are needed for a realistic determination of evaporation integrated over the entire basin taking into account above-mentioned processes. Because of changes in the snow and ice area distribution in the past decades and in the frequency of evaporation periods a significant negative trend in actual basin evaporation is expected in this high-alpine non-vegetated environment. The trend of the residual in Table 1 supports this hypothesis towards decreased evaporation values.

### *Summary of all Water Balance Terms*

In Fig. 5, all the terms of water balance – with the sole exception of evaporation – are presented for the last three decades. Basin precipitation is the only component showing no significant trend over this period, whereas the change in glacier storage leads to continuously rising discharge amounts. In this figure, all the terms are based on measurements and extrapolations using the methods described in Table 1.

*Table 1: Mean yearly sums [mm] of water balance terms for the Vernagtferner basin ( $A = 11.4 \text{ km}^2$ ) between 1974/75 and 2004/05 ( $n=32$  years) along with estimated errors. In addition the early part (1974-1985) is given, characterized by a balanced glacier mass budget, and the most recent period (1994-2005) with a marked negative mass budget. See also Fig. 5.*

Period	Precip. P	Runoff R	Evap. E	Glacier MB $\Delta S$	Res. $\epsilon$
1974–2005 Total of 32y	$1525 \pm 150$	$1790 \pm 90$	$120 \pm 20$	$-305 \pm 30$	$-80 \pm 180$
1974–1985	1463	1399	120	-13	-43
1994–2005	1617	2056	120	-449	-110

### *Summary*

The long-term monitoring programme of the Commission for Glaciology of the Bavarian Academy of Sciences and Humanities has produced a comprehensive database which assists the study of global warming impact on the hydrology of high alpine environments. The strong trend towards more negative summer mass balances makes it necessary to continue this monitoring and modelling effort in order to assess the consequences of glacier mass changes on runoff yield and flood potential (Braun and Weber, 2006). Complementary process-orientated studies such as those presented by Weber (2005) are necessary to gain further insight into the climate-glacier relationship.

### *Acknowledgements*

Numerous helpers were needed to collect the data set, on which this analysis is based. Only a few names can be mentioned here: Oskar Reinwarth, Hermann Rentsch and Erich Heucke. The funding from various sources, such as DFG, BMBF, the Thiemig Foundation, Munich Re, the Academy Research Programme III.B.1 of the Federal Republic of Germany and the State of Bavaria is gratefully acknowledged.

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# How will the Alps Respond to Climate Change? Scenarios for the Future of Alpine Water

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## *Introduction*

The climate of the Alps is highly complex, due to the interactions between the mountains and the general circulation of the atmosphere. The ridges have an average elevation of 2500 m above sea level with a maximum up to 4800 m and as such are a barrier for atmospheric circulation. Another cause of complexity inherent to the Alps arises from the competing influences of a number of different climate regimes in the region, namely Mediterranean, Continental, Atlantic and Polar (Beniston, 2005a). The alpine ridge separates the maritime temperate from Mediterranean climate and creates its own regional climatic conditions. The combination of complex orography and climatic gradients leads to a great variety of environmental conditions with strong gradients over short distances. The Alpine climate is closely related to the intensity and persistence of weather patterns such as the wintertime Scandinavian and Russian high pressure zones and the influence of the North Atlantic Oscillation (NAO). Particularly during the wintertime, the NAO is correlated positively with Alpine temperatures and negatively with precipitation. The Alps often experience extreme weather events such as heavy precipitation, hail and drought, according to the nature and persistence of the associated circulation patterns. Strong rainfall events commonly lead to flooding and landslides, rock falls and debris flows within regions of complex topography. Other forms of extremes that are encountered in the Alps include strong winter wind storms and heat waves. Such climate events may occur in the vicinity of populated regions, causing huge impacts in human and economic terms.

Alpine climates have undergone significant change over the past century, mostly because enhanced radiative forcing due to anthropogenic greenhouse gases (Houghton et al., 2001). Temperatures have risen by up to 2 °C in many parts of Alps between 1901 and 2000, which is well above the global-average 20th century warming. Precipitation trends are more spatially variable, since the response of precipitation to warmer climatic conditions is more subtle than the change in temperature. The recent warming trend in the Alps already produced symptoms such as reduced snowfall, retreating glaciers, and increased rock falls that can be expected to worsen with climate change (IPCC, 2007).

*Summary of observed climate changes in the Alps*

The Alps are particularly sensitive to climate change, and recent warming has been roughly three times the global average. The years 1994, 2000, 2002, and particularly 2003 have been the warmest on record in the Alps in the past 500 years. Durand et al. (2007) report that in the French Alps at around 2000 m a.s.l. temperature trends are most pronounced. Temperatures are rising in spring, but falling in autumn. Particularly late winter and early summer temperature during recent years remained constantly high.

Unlike temperature, precipitation variation over the European Alps showed no significant low-frequency trend and increased uncertainty back to 1500. Precipitation shows considerable spatial differences according to seasonal mean features as well as according to short-term and long-term variability. However the year 2003 was likely the driest in the context of the last 500 years.

As a general trend the annual precipitation is slightly rising in the French Alps, mainly due to rises in summer. Year-to-year variability is big and trends remain uniform at varying elevations. In northern massifs, snow precipitations trends follow the temperatures changes. Snow parameters in the Alps are characterised by a marked declining gradient. The duration of continuous snow cover is clearly declining at all elevations and the snow cover melts much earlier.

Climate variability patterns in the complex terrain of the Greater Alpine Region (GAR) in the last two centuries were also analysed by Bohm et al. (2006) in the frame of the RTD-project ALP-IMP. Annual sunshine totals show a clear trend of significant “brightening” at high elevations (2000-3500m altitude) in the 20th century, whereas the elevations below 1000 m. show weaker to not significant sunshine trends. Cloudiness trends confirm the decadal scale sunshine features. Annual mean air pressure series, averaged over all low elevations show no significant trend but at all high elevation sites there is an increasing trend in the last century. Like in other studies, precipitation showed outstanding regional trend differences. Particularly between the NW versus the SE part of the Alps – obviously caused by the obstacle of the alpine chain – the trends of the last 150 years even show an opposite sign with a 10% increase in the NW and a 10% decrease in the SE of the GAR. It is interesting that some long-term trends have abruptly changed into their opposite in recent times. In the SE winter precipitation is decreasing again since 1980, while autumn precipitation is increasing since 1990.

The effects of global warming on the cryosphere of the Alps are most visibly manifested in the shrinkage of mountain glaciers and in reduced snow cover duration. From 1850 to 1980, glaciers in the European Alps lost approximately one third of their area and one half of their mass (EEA, 2004).

However, the responses to warming are by no means linear. For example, warmer winters imply higher atmospheric moisture content and more snowfall is associated with an overall increase in precipitation. For example in the Alps, exceptional mass loss during 2003 removed an average of  $2500 \text{ kg m}^{-2}$  over 9 measured Alpine glaciers, almost four times more than the mean loss from 1980 to 2001. This was due to high air temperatures over a long period, extremely low precipitation, albedo feedback from Sahara dust depositions, and a previous series of negative mass balance years.

### *Projected climate changes*

In this century, the warming in the Alps is projected to continue at a rate somewhat greater than its global mean. Under the A1B scenario, the simulated area and annual mean warming from 1980–1999 to 2080–2099 varies from 2.2 to  $5.1^\circ\text{C}$  with a median of  $3.5^\circ\text{C}$ . In most models, circulation changes enhanced the warming in winter (due to an increase in westerly flow) and late summer (due to a decrease in westerly flow). Several studies indicated increased temperature variability in summer, both on inter-annual and daily time scales and reduced temperature variability in winter. The number of frost days is very likely to decrease. For every  $^\circ\text{C}$  increase in temperature, the snowline will on average rise by about 150 m, but at lower elevations the snowline is very likely to rise by more than this average estimate. For a  $4^\circ\text{C}$  shift in mean winter temperature in the Alps, as projected by recent RCM simulations for climatic change under a strong emissions scenario (the IPCC A2 emissions), snow duration is likely to be reduced by 50% at altitudes of 2000 m, to 95% at levels below 1000 m. Hantel and Hirtl-Wielke (2007) studied the sensitivity of the Alpine snow cover to temperature and established that a rise of the European temperature by  $1^\circ\text{C}$  has the potential to reduce the duration of snow cover at elevations of extreme sensitivities in certain regions by about 33% in the winter season. This corresponds to a maximum reduction of the snow cover of 30 days in winter at a height of 700 m for  $1^\circ\text{C}$  warming. Some models predict an increase in winter-time precipitation, but it does not compensate for the change in temperature.

Projected monthly changes of temperature and precipitation based on an ensemble of climate change scenarios produced by the Swedish Rossby Centre as a contribution to the PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects) project (Räisänen et al., 2004) are shown on Fig 1. Simulations using two driving global models (HadAM3H and ECHAM4/OPYC3) and two IPCC SRES emission scenarios (A2 and B2) resulted in four realizations of climate change from 1961–1990 to 2071–2100.

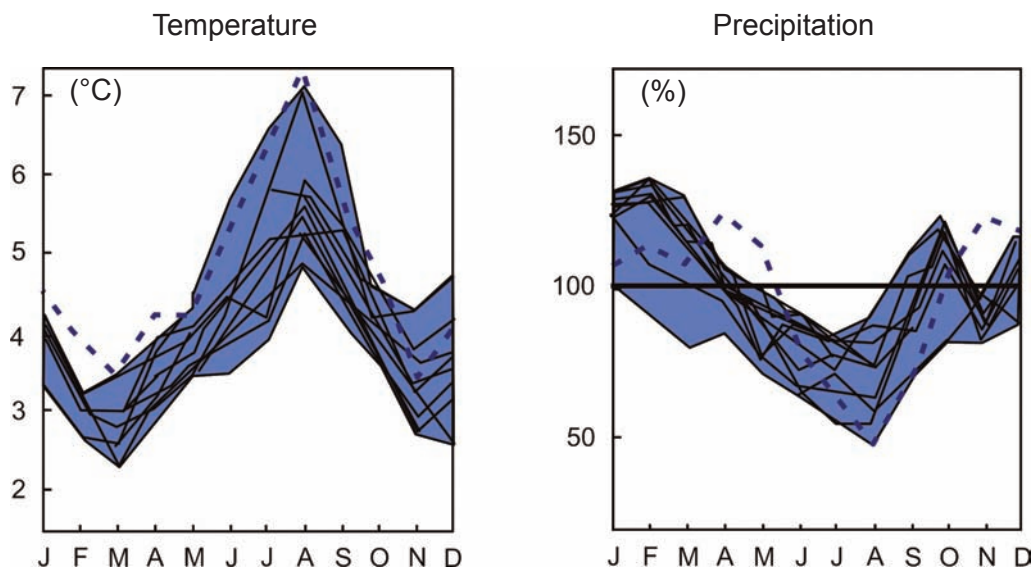


Fig. 1. Signal in 2m-Temperature (left) and precipitation 2071-2100 minus 1961-1990, A2 scenario for Alpine region (modified from Jacob (2006))

Changes in the pattern of precipitation may have an even greater impact than rising temperature. Unfortunately projections of changes in precipitation patterns in mountains are tenuous in most GCMs because the controls of topography on precipitation are not adequately represented. Climate models results indicate a south-north contrast in precipitation changes across Europe, with increases in the north and decreases in the south. The annual mean change from 1980–1999 to 2080–2099 in the worst case scenario A1B is from  $-4\%$  to  $-27\%$  in the Alpine area. In summer, most models simulate decreased precipitation south of about  $55^{\circ}\text{N}$ . The most consistent and largest decreases occur in summer, with increasing evaporation, but the area mean winter precipitation also decreases in most models. Changes in precipitation will vary substantially on relatively small horizontal scales in Alpine areas of complex topography. The details of this variation depend on changes in the future atmospheric circulation. Much larger changes are expected in the recurrence frequency of precipitation extremes than in the magnitude of extremes (Beniston et al., 2007). Changing runoff from glaciers will cause initial increases in total glacier runoff and peak flows, and considerable amplification of diurnal melt runoff amplitudes, followed by significantly diminished runoff totals and diurnal amplitudes as the glaciers continue to shrink.

*Impacts on the hydrological cycle in the Alps*

A warming climate as projected will enhance the hydrological cycle in the Alps. This implies higher rates of evaporation and a greater proportion of liquid to solid precipitation. These physical mechanisms, associated with potential changes in precipitation amount and seasonality, will affect soil moisture, groundwater reserves, and the frequency of flood or drought episodes. These imply serious consequences for water circulation and water management in the Alps: rainfall would decrease in summer and increase or become more intense in winter. In addition, the snow line would rise by 200 metres by 2050 and glaciers would continue to melt. Accordingly, floods in medium and low-lying regions would increase both in intensity and in frequency during winter. On the other hand, in summer, especially south of the Alps there would be more frequent droughts. Lakes in the alpine regions are particularly sensitive to climate change. At the same time, these are the areas where the highest and most rapid temperature increase is expected. Response of lakes to climate forcing is a high probability for earlier ice-out, increase of lake temperatures, and stronger thermal stratification in a warmer future. Chemical regime of lakes (e.g. accelerated eutrophication, increase in water colour, and decrease in oxygen availability) is also likely to change. Because of complex interactions, biological changes induced by climate change are still uncertain. Small variations in climate can have dramatic effects on biota, especially in the Alps where many species, living at the limit of their capabilities, will perish (Eisenreich, 2005).

The duration of snow cover is expected to decrease by several weeks for each degree of temperature increase in the Alps region at middle elevations (Martin and Etchevers, 2005). An upward shift of the glacier equilibrium line from 60 to 140 m/°C is expected. Glaciers will experience a substantial retreat during the 21st century (Haeberli and Burn, 2002). Small glaciers will disappear, while larger glaciers will suffer a volume reduction between 30% and 70% by 2050 (Paul et al., 2004). During the retreat of glaciers, spring and summer discharge will decrease (Hagg and Braun, 2004). The lower elevation of permafrost is likely to rise by several hundred metres. Rising temperatures and melting permafrost will destabilise mountain walls and increase the frequency of rock falls, threatening mountain valleys (Gruber et al., 2004). Changes in snowpack and glacial extent may also alter the likelihood of snow and ice avalanches.

### *Other important impacts*

It is virtually certain that European mountain flora will undergo major changes due to climate change (Walther, 2004). Three responses to climate change can be distinguished at the species level, namely genetic adaptations, biological invasions through species inter-competition, and species extinction. Change in snow-cover duration and growing season length should have much more pronounced effects than direct effects of temperature changes on metabolism. Overall trends show increased growing season, earlier phenology and shifts of species distributions towards higher elevations (Sandvik et al., 2004). Similar shifts in elevation are also documented for animal species (Hughes, 2000). The treeline is predicted to shift upward by several hundred metres (Alcamo et al., 2007).

These changes, together with the effect of abandonment of traditional alpine pastures, will restrict the alpine zone to higher elevations (Dullinger et al., 2004), severely threatening nival flora. The composition and structure of alpine and nival communities are very likely to change (Walther, 2004). Mountain regions may additionally experience a loss of endemism due to invasive species. Similar extreme impacts are expected for habitat and animal diversity as well, making mountain ecosystems among the most threatened in Europe (Schröter et al., 2005). Another major problem in many parts of the European Alps is that ecosystems have been so fragmented and the population density is so high, that many options for ecosystem conservation may be impossible to implement.

Climate change is likely to have both direct and indirect impacts on tourism in Alps (Beniston, 2005b). Direct impacts refer to changes in the climatic conditions necessary for specific activities. Indirect changes may result from both changes in mountain landscapes and wider-scale socio-economic changes such as patterns of demand for specific activities or destinations. Regions whose average altitude lies between 900–1200 m, would experience much-reduced periods with adequate snow-cover whereas the elevated ski resorts in the central and southern Alps would remain relatively unaffected. Such impacts might be partially offset by new opportunities in the summer season and also by investments in new technology, such as snow-making equipment, as long as climatic conditions remain within appropriate limits. Mountaineering and hiking may provide compensation for reduced skiing, and thus certain mountain regions would remain attractive destinations. Higher temperatures may imply longer summer seasons and a new range of outdoor activities may emerge as a consequence.

## *Conclusions*

Climatic change in the Alps is a complex mix of short- to long-term forces, related to the intensity and persistence of weather patterns and enhanced radiative forces due to anthropogenic greenhouse gases. The Alps are particularly vulnerable to climate change. The recent warming trend is now producing symptoms such as reduced snowfall, retreating glaciers, and increased rock falls that can be expected to worsen with climate change. Changes in the pattern of precipitation may have an even greater impact than rising temperatures. Projected changes for mountain regions suggest that the European Alps are likely to have slightly warmer winters with more precipitation than previously while the summer climate may become much warmer and drier than today. It seems likely that alpine climate change will lead to changes in timing and amount of run-off in European river basins and that floods and droughts will become more frequent. The projected decline in precipitation in the Alps plus rise in temperature could produce a 40-70% reduction in runoff. Summer discharge of Alpine catchments will significantly decrease and winter floods will become more frequent. Because the Alps are the primary source for such major rivers as the Rhine, Rhone, Po, and Danube, the impact of reduced mountain precipitation would be felt far beyond the mountainous regions themselves.

Violent storms and fires may increase. Even if they do not increase in frequency, they may increase in intensity. Weather patterns could even develop heavy torrents on exposed slopes leading to erosion and flooding. Erosion would be particularly bad if forests become further weakened by drought. Disasters, such as the outburst of ice- or moraine-dammed lakes, could also be expected.

Ecological zones will tend to move uphill and many nival zone plants species will be threatened or disappear. Even in lower zones, many species may prove unable to adapt as their habitats migrate. Forests will be especially hard-hit. Pollination, flower production, and seed germination - would be upset by climate change. Warmer temperatures would encourage insects and biological pathogens that attack trees, killing or weakening them.

Mountain economies, especially the skiing industry, may be undermined through climate changes. The economy of Alpine mountain areas has been, for a few decades now, mostly dependant on tourism, particularly during winter as snow sports have become a significant source of income. Drier conditions would also undermine energy and water supplies, and health conditions. A general melting of the permafrost may impair existing transport and housing infrastructure. Alpine agriculture is one economic sector that may benefit from global warming, although southern slopes may suffer from severe drought.

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Facing climatic change, it is necessary to plan in terms of decades. Some of the impacts that can be expected in the Alps may not become apparent for years to come. The policies and decisions related to climate change may also provide opportunities and challenges for the private and public sectors. A carefully selected set of national and international responses aimed at mitigation, adaptation and improvement of knowledge can reduce the risks posed by climate change. The expected hydrological changes in the Alps may be drastic and they need to be taken into account for the long-term integrated management of water resources. This includes disciplines such as spatial planning, environment and agriculture etc. International cooperation and free and unlimited access to data and information are mandatory.

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# Water Problems at the European Scale – The EURO-LIMPACS Project

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## *Introduction*

Freshwater systems have been already under stress from land-use change and pollution for years and decades. They are now facing additional pressure from changes in climate, acting directly and through interaction with other drivers like nutrient loading, acid deposition, toxic pollution or land-use change. Both anthropogenic and climate impact pose considerable threats on the quality and availability of freshwaters.

In 2004 the integrated project EURO-LIMPACS was launched to evaluate the impacts of future global change on European freshwater ecosystems. The project is funded by the European Union under the 6<sup>th</sup> Framework Programme and the Thematic Sub-Priority “Global Change and Ecosystems”. It brings together 36 partners across Europe, including Russia and Canada and is co-ordinated by the **Environmental Change Research Centre**, University College London, UK. EURO-LIMPACS is relevant to the Water Framework Directive and supports the EU Charta on Sustainable Development.

The paper gives a brief description of the EURO-LIMPACS work programme and will focus on selected topics, which are or can become relevant to the Alpine region.

## *Project summary*

EURO-LIMPACS focuses on key drivers of aquatic ecosystem change, which are climate change, hydromorphology and land-use change, acid deposition, nutrients and toxic substances. It examines the interactions of these drivers on freshwater ecosystems. The project includes rivers, lakes and wetlands and seeks to integrate ecosystem functioning at the catchment scale. It considers different time scales from episodes and events to seasonal cycles and decades. EURO-LIMPACS uses experiments including laboratory and whole system manipulations, time-series analysis of long-term datasets from key sites across Europe, space-time substitution, palaeolimnology to reconstruct natural variability and past reference conditions, and dynamic modelling to simulate specific driver-response systems

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and catchment scale processes. The project also aims to derive indicators of aquatic ecosystem health, which are suitable to identify and monitor impacts of climate change. It seeks to define reference conditions and restoration targets, and to develop practical management tools based on a decision-support system to advise users and stakeholders.

EURO-LIMPACS tries to cover a wide geographic and climatic range (Fig. 1), with sites distributed from the north to the south of Europe, from maritime to continental and from lowlands to the alpine region.

The work program is structured in 10 work packages, five of which deal with driver-response processes in freshwaters and their interaction with climate change. One work package is concerned with the development of a model tool-kit to simulate hydrological, hydrochemical and ecological processes and their interaction with global change at catchment scale. Work packages 6-9 seek to develop indicators, restoration strategies and a decision support system, and WP 10 deals with the transfer of knowledge internally within the project and externally with the user community and wider public. More information on EURO-LIMPACS is available under <http://www.eurolimpacs.ucl.ac.uk>.



*Fig. 1: Key regions of EURO-LIMPACS, marked with white ellipses*

Out of the wide range of EURO-LIMPACS objectives, a few topics are selected and described here. They already are or may become relevant for freshwaters in the Alps under a changing climate.

### *Stratification of lakes*

An increase in air temperature is generally reflected in higher lake water temperatures. The heat balance of a lake and the distribution of heat within a lake are largely determined by meteorological forcing across the air-water interface (e.g. Imboden and Wüest, 1995). Changes in climate (like changes in air temperature, radiation, wind, humidity, precipitation) are therefore expected to alter temperature profiles, thermal stability and mixing patterns in lakes. As a consequence, the distribution of dissolved oxygen and nutrients will change and that way impact on phytoplankton communities and primary production.

The extraordinary warm summer 2003 is often taken as an example for what might occur during an average summer by the end of the 21<sup>st</sup> century. Meteorological data from Zürich (Switzerland) revealed, that the mean summer air temperature (June through August) in 2003 exceeded the corresponding long-term average (1856-2002) by 4.4°C or by 5.4 standard deviations  $\sigma$  (Jankowski et al., 2006). This situation compares to the increase in air temperature of up to 4 °C, which is projected by global climate models for the end of this century (IPCC, 2007).

At Zürichsee and Greifensee, two Swiss lakes in the vicinity of Zürich, water temperatures in the epi- and metalimnion rose by about 2°C in summer 2003 (June – August) and ranged almost 3  $\sigma$  above the long-term mean of 1856-2002 (Fig. 2) (Jankowski et al., 2006).

The resulting high thermal stability of the water column – temperatures in the hypolimnion were close to average - suppressed the downward mixing of epilimnetic water. This had a strong impact on the oxygen content of the hypolimnion and caused oxygen depletion (HOD) to exceed the long term average by more than 7  $\sigma$  in the mesotrophic to weakly eutrophic lake (Zürichsee). The eutrophic lake (Greifensee), on the contrary, experienced almost no change in summer HOD with its already anoxic hypolimnion.

The warm summer 2003 nicely demonstrated, that mesotrophic to weakly eutrophic lakes are likely to be strongly impacted by the intensified stratification, which is favoured by rising air temperatures. Increased deep water oxygen depletion and the ecological consequences like phosphor dissolution from sediments, algal blooms and the release of cyanotoxins may thus counteract management and restoration efforts undertaken in the past to mitigate anthropogenic eutrophication.

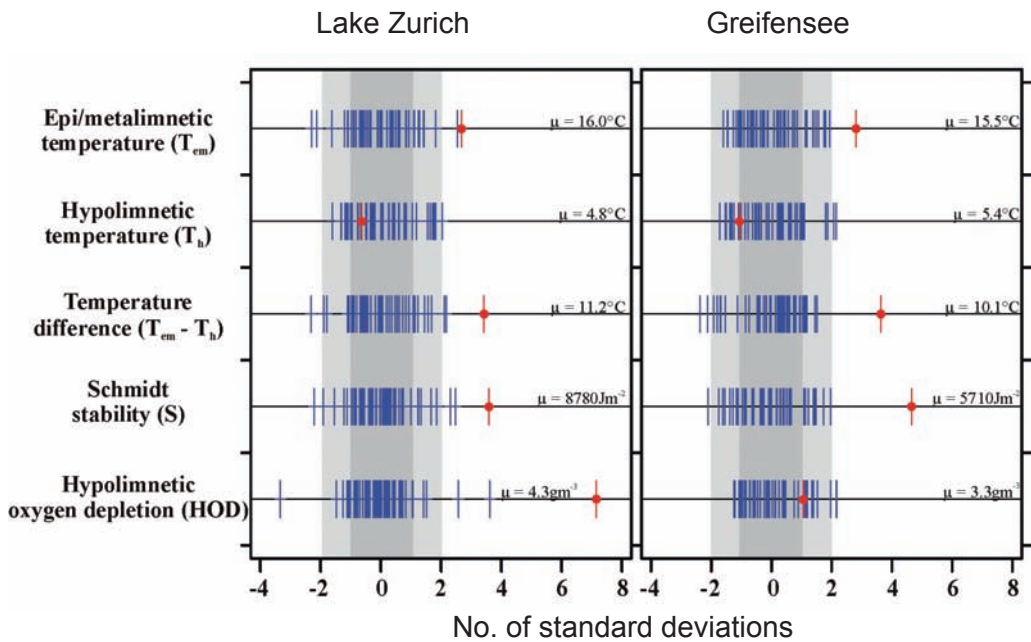
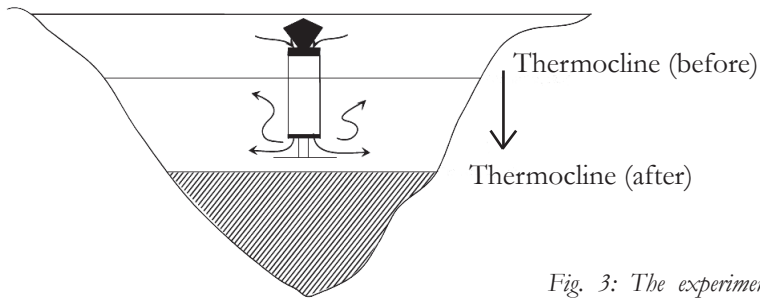


Fig. 2: Standardized values of water temperature, Schmidt stability and hypolimnetic oxygen depletion in Zürichsee and Greifensee (Switzerland). Data are expressed as standard deviations from the long term means  $\mu$  (1956-2002). The summer 2003 values are indicated by red circles. (Figure modified from Jankowski et al., 2006, Copyright 2006 by the American Society of Limnology and Oceanography, Inc.).

The impact of climate change on the thermodynamics of small lakes in forested catchments is currently assessed by the whole lake mixing experiment THERMOS in Finland and Norway. The aim of this field experiment is to study the lake chemistry and biology during the ice-free season by manipulating the lake stratification pattern (thermocline depth) (Fig. 3) with an especially designed equipment (Fig. 4). Results will be compared with the conditions in a so-called reference lake, which will not be manipulated, but is regularly monitored.

The THERMOS experiment simulates the lake response to a lowering of the thermocline under changed climate conditions, i.e. an increase in the input of mixing energy caused by higher wind speeds in a warmer climate. According to IPCC 2007 it is more likely than not (i.e. > 50% probability) that average and extreme wind speeds will increase in northern Europe due to projected changes in the large-scale atmospheric circulation and the increased pressure gradient across Scandinavia.



*Fig. 3: The experimental design of THERMOS (Forsius et al. 2006, Euro-limpacs project)*



*Fig. 4: Mixing equipment used in the Finnish lake Halsjärvi (Forsius et al. 2006, Euro-limpacs project)*

### *Water chemistry in high alpine lakes*

In response to the increase in air temperature in the Greater Alpine Region (Auer et al. 2006), high altitude lakes can experience a substantial change in water composition. At Rasass See (2682 m, Italy), a high alpine lake in a catchment of metamorphic rocks, electrical conductivity has increased by a factor of 18 during the last 2 decades (Fig. 5) and the concentrations of the most abundant ions magnesium, sulfate and calcium have reached the 68-fold, 26- and 18-fold values (Thies et al. 2007).

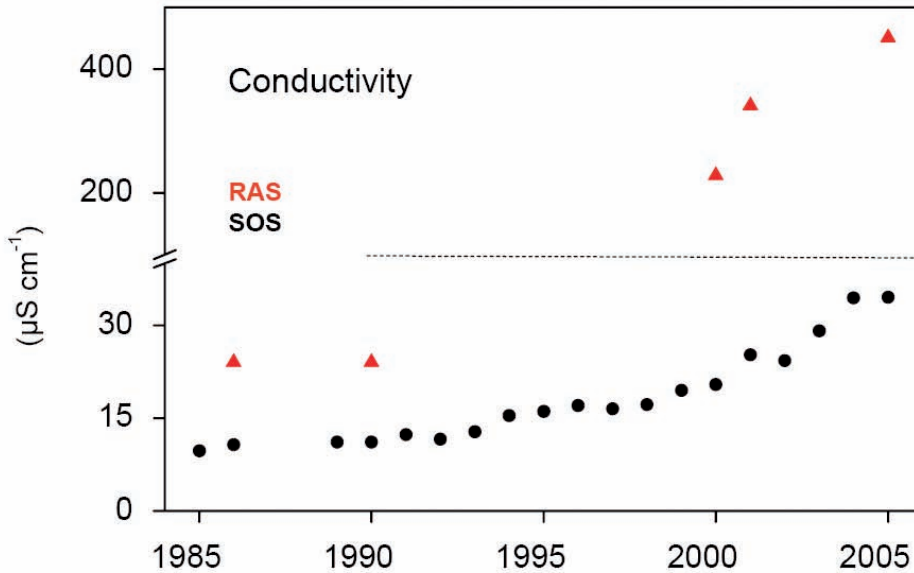


Fig. 5: Conductivity in two alpine lakes in the period 1985 – 2005, Rasass See (RAS: red triangles) and Schwarzsee ob Sölden (SOS: black circles). Horizontal lines indicate a break in the vertical scale. (Modified from Thies et al. 2007, with permission of the American Chemical Society).

The pronounced change in lake water chemistry is attributed to the solute release from an active rock glacier in the catchment of Rasass See (Fig. 6). Melt water draining into the lake has caused solute concentrations to increase since the 1990ies, while the effects of bedrock weathering and atmospheric deposition on lake water chemistry are considered to be negligible.

In addition to the increased amount of major ions, unexpected high nickel concentrations have been found recently. The concentration of  $243 \mu\text{g L}^{-1}$  in the water of Rasass See exceeds the nickel limit for drinking water by one order of magnitude. This high value cannot be related to catchment geology and leaves the original source of nickel still unclear.

Similar but less intense processes have been observed at Schwarzsee (2796 m, Austria). There, electrical conductivity increased by a factor of three during the past two decades (Fig. 5), while nickel concentrations were just above the detection limit. This reduced change in solute concentration compared to Rasass See is attributed to the lower impact of glacial melt water, as the area of active rock glaciers in the catchment of Schwarzsee is smaller and situated at a higher elevation.





*Fig. 6: Rasass See and major parts of its catchment. The white ellipsis indicates the position of the active rock glacier (Foto by V. Mair).*

It is anticipated that high mountain freshwaters become increasingly impacted by melt waters from active rock glaciers (Thies et al. 2007) as they are located near the local boundary of permafrost, thus rendering them sensitive to the projected increase in air temperature (IPCC, 2007).

### *Persistent organic pollutants*

Persistent organic pollutants (POPs) have been introduced anthropogenically to the environment, e.g. through industrial production, pest control and agriculture. Meanwhile, POPs have reached the most remote areas of the Earth, they have become ubiquitous and they persist in the environment (Daly and Wania, 2005). POPs enter into the water cycle, accumulate in soils, plants and organisms, and they may be redistributed by various processes like erosion, leaching or mineralisation of organic matter. POPs are known to accumulate in cold environments as a result of progressive volatilization from warm source regions and condensation in colder regions (e.g. Wania and Mackay, 1996; Blais et al., 2001; Grimalt et al., 2001, Carrera et al., 2002; Daly and Wania, 2005). Cold trapping of the less volatile compounds increases with decreasing temperature, i.e. at high latitudes and in high altitude headwater catchments.

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Their properties – POPs are semi-volatile, chemically stable and hydrophobic - favour the long-range transport and world-wide distribution. Organochlorine compounds like hexachlorobenzene, hexachlorocyclohexanes (HCHs), endosulfanes, dichlorodiphenyl-trichloroethanes (DDTs) and polychlorobiphenyls (PCBs) are among the pollutants of greatest concern. In particular their hydrophobicity causes POPs to become strongly assimilated by biological tissues and as they are rather resistant to biodegradation, they can be substantially biomagnified in food chains including men (Blais et al., 2001). Many POPs have been classified to be harmful, toxic or carcinogenous for humans (e.g. Blais et al., 2001; ATSDR). Therefore some of these substances have been banned like the PCBs, which were frequently used as coolants and lubricants in electrical equipment. But nevertheless, some POPs are still used as insecticides in agriculture like endosulfanes or lindane ( $\gamma$ -HCH). Recently, the World Health Organization (WHO) has even recommended the re-introduction of the previously banned DDT in order to improve malaria control (e.g. by indoor residual spraying in sub-Saharan Africa) (WHO, 2006).

Substantial knowledge gaps still prevail on the distribution of POPs in the natural environment, on food contamination and bioaccumulation (Porta and Zumeta, 2002; Daly and Wania, 2005). EURO-LIMPACS seeks to establish whether climate change could increase toxic pollutant input to freshwaters in Europe. Climate change is expected to impact on the distribution patterns and the mobility of organic pollutants in freshwater systems and it may lead to changes in the uptake and accumulation of POPs in freshwater food chains. Future changes in climate may influence the remobilization of POPs in high mountain regions and from glaciers (Blais et al., 2001; Daly and Wania, 2005).

### *Release of dissolved organic carbon*

Dissolved organic matter (DOM) is a wide spread component of natural waters and comprises a huge amount of different compounds. It is generated by partial decomposition of organisms and may be stored in soils for a varying length of time. A well-known aspect of DOM in water is the characteristic brown colour due to the absorption of visible light by humic substances. As part of DOM, the concentration of dissolved organic carbon (DOC) is frequently determined in natural waters and ranges from  $<1$  to  $>50$  mg L<sup>-1</sup> (Thurman, 1985). The lowest values are observed in groundwater and so-called clear-water lakes and rivers draining from bare rock, while concentrations are high in freshwaters draining peat and wetlands.

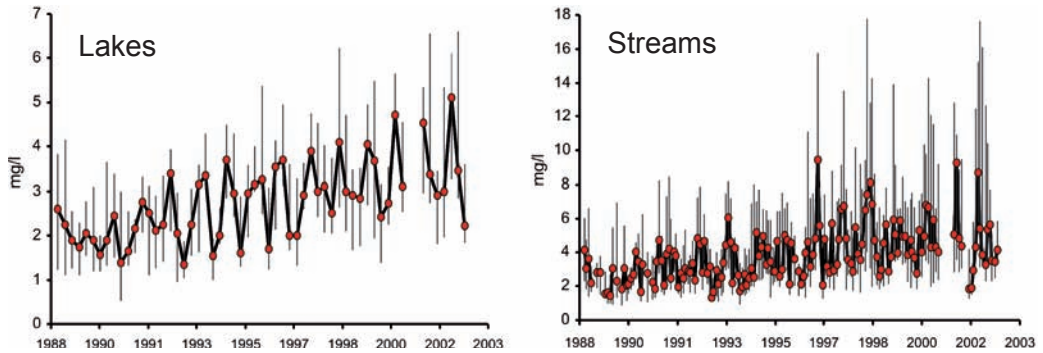


Fig. 7: Average DOC concentration ( $\text{mg L}^{-1}$ ) at 10 lakes and 8 streams in the UK Acid Waters Monitoring Network, 1988 to 2003. Bars indicate the 25<sup>th</sup> and 75<sup>th</sup> percentile concentrations at each sampling interval. (Figure modified from Evans et al., 2006)

Recent studies have revealed rising trends of DOC concentration across large areas of North America and Europe (e.g. Freeman et al., 2001; Stoddard et al., 2003; Vuorenmaa et al., 2006; Evans et al., 2005 and 2006). In the UK, DOC concentrations in lakes and streams have almost doubled since 1988 (Fig. 7), while for Finnish lakes an average increase of total organic carbon (TOC) by about 0.1 to 0.2  $\text{mg L}^{-1}$  per year is reported (Fig. 8).

The increase in surface water DOC is likely driven by a combination of changing climate, in particular the increase in air temperature and changes in drought-rewetting cycles, the recovery from acidification and changes in sea-salt deposition in coastal regions. However, the debate on the main drivers of DOC increase in surface waters is still ongoing.

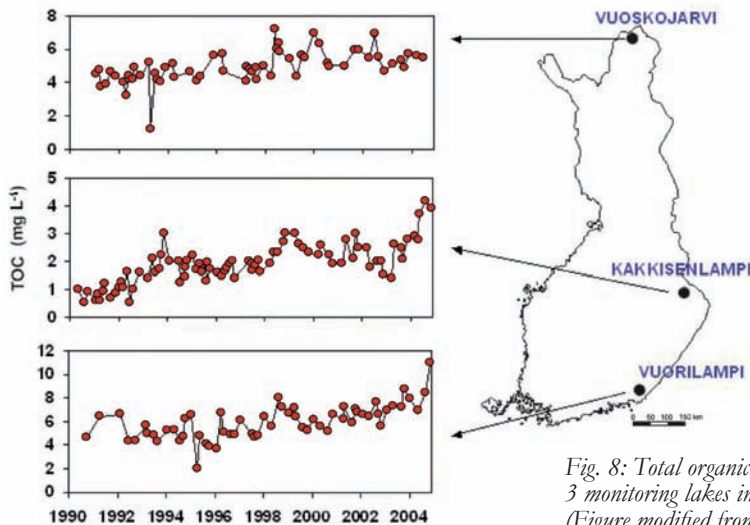


Fig. 8: Total organic carbon concentration (TOC) at 3 monitoring lakes in Finland. (Figure modified from Vuorenmaa et al., 2006)

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In the Alps, DOC concentrations in groundwater and surface waters prevail in the lower range (e.g. 0.2 – 2 mg L<sup>-1</sup>). Changing climate conditions could enhance the DOC export from forested mountain catchments to freshwaters, similar to what has been reported for Northern and Western Europe. For instance, it is anticipated, that major precipitation events will cause peak DOC values in surface waters draining from forested mountain catchments.

Within the EURO-LIMPACS project climate impacts on DOC levels in surface waters are investigated running manipulation experiments, which simulate for instance nighttime warming and increasing drought frequency or the effect of soil frost depth on DOC concentration and bioavailability. Catchment-scale modelling concerned with the relation of surface water DOC and the organic matter content of soils seeks to predict changes in the DOC export from different landscape types. To establish natural DOC variability prior to 1850, a relationship between diatom species, irradiance and DOC will be reconstructed.

### *Reference conditions*

Reference conditions are defined as the ecological conditions found at undisturbed or minimally disturbed sites. For practical reasons, conditions existing before the onset of intensive human activities like agriculture, forestry, large-scale settlements and industrial production are also defined as reference conditions (Battarbee et al., 2005). As the landscape of Europe has been altered for centuries, the identification of pristine ecosystems is no trivial task. Aquatic resources are deteriorating at an alarming rate due to anthropogenic stresses like overexploitation, eutrophication, acidification and alterations in morphology and hydrology. Therefore, the European Community agreed on a set of measures to maintain or restore the integrity of freshwaters. In this context, the European Water Framework Directive (WFD) requires the use of reference conditions for the ecological assessment of inland waters across Europe.

The evaluation of the rate of change in freshwater ecosystems for sub-decadal or even annual time periods can be performed by paleolimnological analysis of lake sediment cores. This analysis addresses a variety of chemical and biological parameters, e.g. algal nutrients, fossil pigments, diatoms, cladocera and chironomid remains. The combination of recent limnological time-series with paleolimnological data supports the elaboration of reference conditions.

In a stable climate, reference conditions established using either time or space approaches can be used to define restoration targets. However, under a changing climate, it is anticipated that the baseline represented by the reference state may be altered, which complicates the determination of reference conditions in the assessment of degradation and recovery of freshwater ecosystems. This is illustrated in Figure 9.

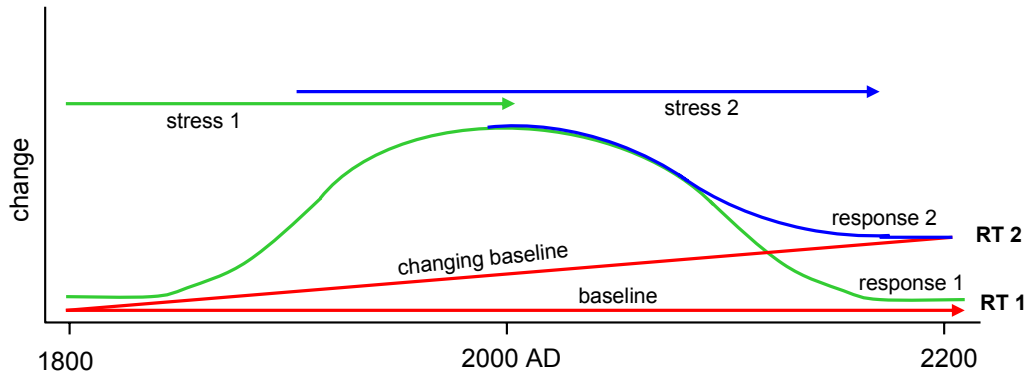


Fig. 9: Idealised diagram illustrating the response of a system to increasing and decreasing stresses and the potential change in targets (RT1 and RT2) for ecosystem recovery resulting from a change in the boundary conditions. (Modified from Battarbee et al., 2005)

A freshwater system, which is exposed to an anthropogenic stressor (“stress 1”) for a certain period of time, will gradually deviate from baseline conditions. Ceasing stress and restoration strategies will help the system to recover (“response 1”) and to return to baseline conditions, i.e. restoration targets (RT1). Often, a system is impacted by more than one stress factor and the overall response will further deviate from baseline conditions (in Figure 9 this is indicated by the line “response 2”). Climate change may shift the baseline and restoration targets have to be re-defined (RT2).

EURO-LIMPACS seeks to establish and validate reference conditions and restoration targets for different ecosystem types across Europe. It evaluates current restoration strategies and the impact of climate change on ecosystem recovery and restoration targets.

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# The River Continuum Concept revisited: Lessons from the Alps

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*Historical perspective: from the view of rivers as a clinal zonation to rivers as dynamic ecosystems*

The distribution of organisms, resources, and biological processes change along rivers and depend on large-scale processes (e.g. climatic, hydrologic, geomorphologic) as well as local ones (e.g. biotic). The first attempt to categorize such discontinuities is the Stream Zonation Concept (Illies & Botosaneanu 1963), which defined a series of distinct communities along rivers, separated by major faunal transition zones (e.g. the rhithral–potamal transition). A more ecological perspective was introduced later by Vannote et al. (1980) with the River Continuum Concept, according to which resources change along a clinal (rather than zonal) gradient which predictably structures the stream biota. The River Continuum Concept explained the changes in biological communities only along the longitudinal dimension of the river, on the basis of its relationships with the terrestrial habitats, based on the observation that in small mountain streams below the tree-line, due to the shading effect of riparian vegetation, leaf input (Coarse Particulate Organic Matter, CPOM) largely exceeds primary production, heterotrophy is dominant, respiration is higher than photosynthesis ( $P/R < 1$ ), and macroinvertebrate communities are dominated by shredders and collectors. Moving downstream, the rivers increase in width and discharge, and the importance of riparian vegetation (as CPOM and shading effect) decreases, leading to an autotrophy-dominated system ( $P/R > 1$ ); as a consequence, macroinvertebrate communities are dominated by grazers and collectors. In large floodplain rivers, turbidity and unstable sandy riverbeds limit photosynthesis and the system reverts to heterotrophy ( $P/R < 1$ ) due to abundant Fine Particulate Organic Matter (FPOM) coming from upstream, and macroinvertebrate communities are dominated by collectors, filter-feeders, and few predators. Thus, the River Continuum Concept underlined how river communities and river metabolism are influenced not only by local conditions, but also by processes occurring upstream. The zonation and the River Continuum concepts provided an essentially unidirectional (longi-

## The Water Balance of the Alps

tudinal) perspective, whereas the importance of the lateral, vertical and temporal dimensions were later highlighted in the Hyporrheic Corridor Concept (Stanford & Ward 1993), which took into account the dynamics between the river channel, the groundwater domain and the alluvial corridor. The morphologically homogeneous river channel defines the limits of the strictly “running water” ecosystem, at least for its longitudinal dimension. However, the hydrological and functional connections between the river and the riparian zone extend to the entire alluvial bed (with its permanent and temporary wetlands, which play an important role as reproductive and nursery areas for fishes, and as areas of pulsing nutrients exchange), where changes in groundwater level influence vegetation cover (which in turn affects trophic inputs, shading, and the morphological evolution of the river). These connections represent the lateral dimension. The vertical dimension refers to the exchanges between surface water and groundwater. The hyporheic zone, i.e. the saturated interstitial areas beneath the stream bed and into the stream banks that contain some proportion of channel water (White 1993), is now recognized as an integral component of the stream, where important biogeochemical processes take place, and which hosts very complex and specialized invertebrate assemblages. The characteristics and the interconnections among habitats along these three spatial dimensions vary over the temporal dimension, both on short scale (variations in hydrological regime) and long scale (morpho-dynamic evolution of rivers), thus maintaining the constant variations of river dynamics which support the functioning of aquatic ecosystems.

The role of disturbance in fluvial ecosystem has been taken into account in recent times. It is recognized that the lack of disturbance suppresses biodiversity (Pickett & White 1985); river ecosystems in the natural state are very dynamic, but in much of the world the natural disturbance regime has been largely eliminated by a variety of river regulation measures. The importance of disturbance represented by alternating dry and wet phases in enhancing biodiversity and productivity in rivers was integrated in the Flood Pulse Concept (FPC), (Junk et al. 1989), a comprehensive approach focusing on river floodplain dynamics. The FPC describes the rivers and their associated floodplains as integrated components of a single dynamic system, linked by strong interactions between hydrological and ecological processes. The major driving force is the pulsing of river discharge that determines the degree of connectivity and the exchange processes of matter and organisms across river floodplain gradients. The focus is, therefore, on the lateral and temporal dimensions. The FPC was, however, derived mainly from research carried out in large tropical river systems with a predictable flood pulse of long duration (Junk 1997). The model was extended to temperate running waters, to floodplains situated in upper and middle reaches, and to expansion/contraction cycles below bankfull in the Flow Pulse Concept (Tockner et al. 2000), which also underlines the role of temperature as a major determinant of floodplain

ecology. According to this model, habitat heterogeneity is mainly a product of shifting water sources, different flow paths and the relative importance of autogenic processes.

At the floodplain scale, matter (including organisms) and energy are exchanged between different units of the riverine landscape because of hydrological connectivity (Amoros & Roux 1988). Floodplain water bodies differing in connectivity with surface waters of the main channel host different biotic communities. The degree of connectivity between ground waters and surface waters also is an important determinant of functional processes in aquatic and riparian systems (Brunke & Gonser 1997; Ward et al. 1998).

From the previous discussion appears that the major contributions of the concepts that developed in riverine ecology in the last 50 years have led to an integrated model of dynamic river ecosystems (Fig. 1). The understanding of ecological processes which develops from this strong conceptual base, will increase the effectiveness of conservation and restoration initiatives. The analysis of the disruption of connectivity of Alpine streams and the definition of the mitigation measures represents one of these cases.

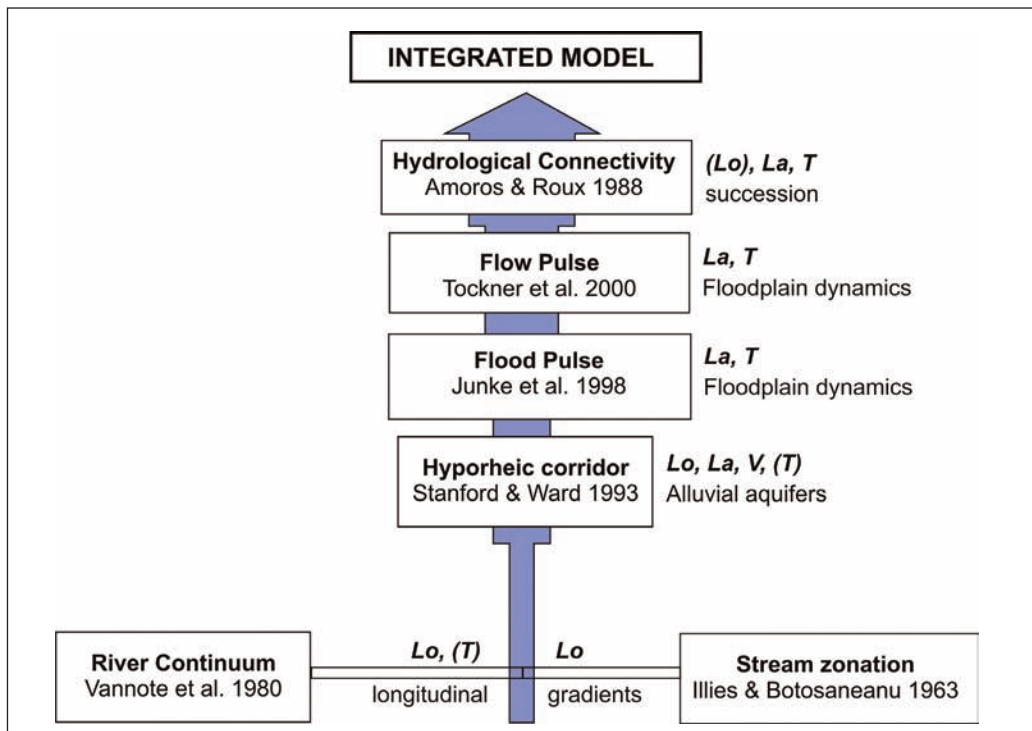


Fig. 1. A modular framework for developing an integrated model of dynamic river ecosystem. Modified from Ward et al. 2002. La: lateral dimension; V: vertical dimension; T: temporal dimension.

*Lesson from the Alps: loss of connectivity due to hydropower production*

All four dimensions of stream ecosystems have been disrupted in Alpine streams to a considerable extent. Man-induced alterations of Alpine streams affect water quality and quantity, and stream morphology. Point-source pollution has been reduced, at least partially, by sewage treatment plants, but nutrients and contaminants from diffused sources are an increasing problem, due to reduction of denitrifying hot spots in buffering riparian corridors. In most Alpine watersheds, agricultural sources contribute to more than 50 % of total nitrate load. River discharge has been severely changed in several Alpine streams by abstraction for hydropower, agriculture, industry, drinking water, artificial snow, thus altering the temporal dimension of the flow regime in its main components (magnitude, frequency, duration, timing, rate of change) with cascading effects on the ecosystem that in turn affect biodiversity and ecological functioning. Channel morphology of Alpine rivers has been modified to a large extent in the past 200 years with cascading effects on the longitudinal, lateral and vertical dimensions. The longitudinal continuity has been fragmented in the last century by the construction of dams meant primarily for hydropower production, and of weirs and embankments for flood protection and erosion control. The lateral connectivity has been altered by the reduction of river channels due to land claiming for agriculture and urbanization. This also caused a decrease in the vertical connectivity between the channel and the aquifer. The hyporheic zone, where water and organic matter exchanges occur, may also be clogged by the reduction of flow and extreme flood events in regulated rivers (Robinson et al. 2004)

Hydrological regime, water quality, and channel geomorphology, are among the most important parameters that limit the distribution and abundance of riverine species, and they vary with stream typology (Poff & Ward 1989; Karr 1991; Cortes 1992; Death & Winterbourn 1995). The natural flow regime is strictly dependent from the geomorphologic, climatic and environmental characteristics of the watershed and its natural changes occur over hours, days, seasons, and years. It is defined by five critical components: magnitude of discharge (amount of water passing per unit time), frequency of occurrence of flow (how often a flow above a given magnitude occurs over a time interval), duration of specific high or low flow conditions, timing or predictability of flows (the regularity with which they take place), and rate of flow change (how quickly flow changes from one magnitude to another) (Poff et al. 1997).

It is thus obvious how changes in water quantity in Alpine streams alter the natural flow. The quantity of available water depends on several natural factors: origin, distance from the source, stream order, geology, climate, and by the cumulative effects of manage-

ment. Management can be summarized in three phases: abstraction, storage, release. The cumulative effect of water abstraction is a reduced discharge, with frequent interruption of superficial flow which disrupt downstream colonisation by drift, isolating benthic communities, with loss of resilience. The lower discharge following abstraction changes temperature patterns (higher summer maximum temperatures and daily variations, winter freezing). This, together with lower water velocity and higher channel stability, favours the development of periphyton, and benthic communities may lose specialist taxa and be dominated by more opportunistic species. In the case of lake inlets, the turnover time of the lake may be affected and changes in the trophic status may occur. Stream typology is not taken into account when selecting water for abstraction. The headwaters of Alpine streams can be originated from glacial melt (kryon), snow/rain melt (rhithron), spring-fed (crenon), and lake outlets. The different origin generates streams with peculiar ecological signature, which host different biological communities (Maiolini & Lencioni, 2001, Milner et al. 2001) which contribute to overall Alpine diversity.

Storage of water in reservoirs and dam effects are well documented (Friedl and Wüest 2002, Poff & Hart 2002) and involve modifications of the chemical and physical parameters of the water, of downstream hydro-morphology and flow regime, creation of barriers to upstream-downstream movement of organisms and nutrients. All this affects the biota of the downstream channel, the riparian areas and related floodplain wetlands. Differently from natural Alpine lakes, reservoirs often release water from the deepest part of the water body and, due to their frequent level fluctuations, they do not host, and export downstream, phyto- and zooplanktonic communities.

Finally the release of turbinated waters to the channel may impose dramatic and sudden changes (hydropiking) not only in discharge, but also in chemical and physical properties of waters. The negative effects propagate for long distances downstream of the power stations (Friedl & Wüest 2002; Wüest 2003), as shown in Fig. 2.

Benthic communities are impacted by water abstraction/diversion and stocking (Armitage 1984; Brittain & Saltveit 1989), and also hydropiking (Cereghino & Lavandier 1998; Cortes et al. 2002). Alpine hydropower plants are typically operated intermittently, being particularly adapted to satisfy peak energy request. Operation of hydropower plants discharging directly in the channel is followed by sudden, frequent and severe changes in discharge, current velocity, turbidity, streambed stability, temperature (Cushman 1985; Allan & Flecker 1993; Maiolini 2006).

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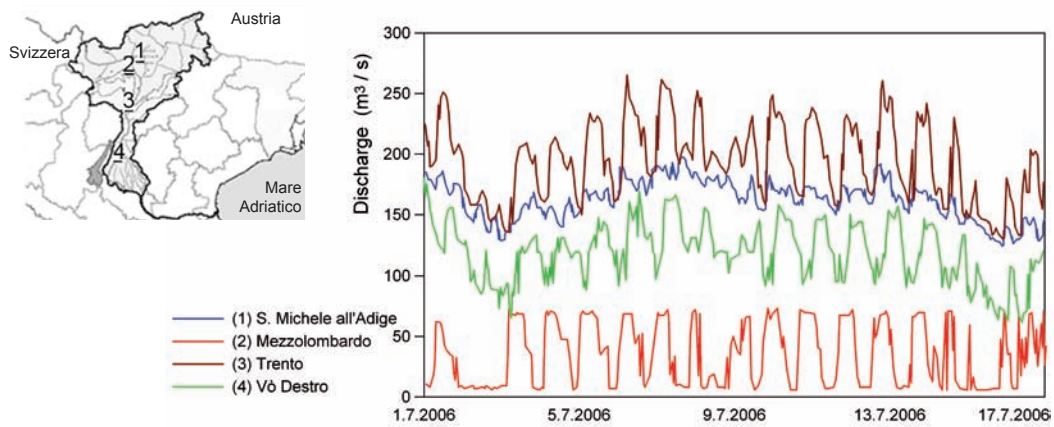


Fig. 2. Effects of hydropowering on the Noce Bianco stream (3<sup>rd</sup> order stream, Trentino, Italy) and propagation of the effects downstream along the Adige River, as shown by hourly discharge data. The hydroelectric power plant releases at Mezzolombardo show a strong hydropowering effect, which propagates to Trento and Vò Destro.

Following an intense development of different methods to calculate Minimum Vital Flow (MVF) in the past decades, scientists now recognize that arbitrary “minimum” flows are inadequate, as the structure and function of a riverine ecosystem and many adaptations of its biota are dictated by patterns of temporal variation in river flows (Richter et al. 1997; Poff et al. 1997; Lytle & Poff 2004). In Alpine streams, the quantity of water depends on the budget of abstraction, release and MVF. Although from a theoretical viewpoint a river needs all the available water to sustain its functioning and support biodiversity, this is not realistic in areas such as the Alps, where tourism, agriculture and hydropower production are the main economic resources. Though hydropower generation at a global scale is a “green” energy source as it produces no greenhouse emissions, it has no dangerous residuals and the “fuel” is free and renewable, at the local scale its impacts on freshwater ecosystems may be severe (Cereghino & Lavandier 1998; Cereghino et al. 2002; Cortes et al. 2002; Maiolini et al. 2006)

The protection of freshwater ecosystems appears paramount if we consider that the rate of biodiversity decline is 5 times faster in freshwater ecosystems (Ricciardi & Rasmussen 1999).

Further still, floodplains represent a minor part of the territory but are vital for a great part of the fauna. For example in Switzerland it has been calculated (Tockner & Ward 1999) that 10% of the fauna is exclusive of floodplains, 40% is found regularly in these habitats and 80% frequents them occasionally. Considering that floodplains cover only 0.76% of the Swiss territory, the effort for their protection results in a very high environmental benefit

in respect to the cost of protecting such areas. Finally, recent research has attempted to assess the economic values of the services provided by natural ecosystems (Kremen & Ostfeld 2005; Costanza & Folke 1997; Costanza et al. 1997). This approach may be a useful contribute in solving specific conflicts arising among policy developers, stake holders and end users of ecosystem benefits, but natural ecosystems should also be protected per se as mankind's undeniable heritage (McCauley 2006).

### *Conclusions and direction for research and management*

In view of natural evolution fostered by contemporary climate change and a foreseen increase in water demand for hydropower and other uses, such as artificial snow production, it is crucial to direct Alpine research to a better understanding of the changes occurring in freshwater ecosystems in order to produce new ecologically sustainable management recommendations.

According to the European Water Framework Directive 2000/60, most river systems impacted by flow alterations may be classified as Heavily Modified Water Bodies and thus would not undergo the rehabilitation measures needed to reach a good ecological status, and would follow a different managing guideline aimed to achieve good ecological potential and good surface water chemical status. For this purpose we need scientifically based tools to classify the effects and the ecological relevance of hydropower impacts and to define possible emendation measures. Topics of particular relevance are: the economic quantification of the ecosystem benefits produced by freshwater ecosystems, the role of headwater streams as hotspots of aquatic biodiversity and core areas for ecosystem functions such as denitrification and recharge of groundwater aquifers, the likelihood of being able to mimic natural flow variability in contrast to the current minimum flow releases.

Scientifically defensible approaches are thus needed to define environmental flows for the complex array of Alpine rivers, and sharing of ecological and hydrological knowledge among the scientific community is urgently needed as extreme climate events are likely to lead to more water- engineering and thus to increasing ecosystem stress (Arthington et al. 2006).

In particular, hydropeaking effects need to be better understood and classified in order to recommend mitigation measures and discriminate the Heavily Modified Water bodies from others than can reach good ecological status.

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Mitigation measures to be taken into account for operational and structural planning of hydroelectric power plans should include the following considerations:

1. Stream typology is not evaluated when selecting waters for abstraction, whereas maintenance of ecological continuity needs to take into consideration the natural sequence of stream typologies. Changes in the abstraction/release point along the river continuum would help to reduce the ecological impacts.
2. Headwater streams have high diversity and most ecosystem functions are maximised. The protection of pristine low order streams of different typologies and the restoration of impacted ones should be a priority.
3. Hydropeaking could be reduced by use of turbinated waters for further hydroelectric production or for other downstream users (irrigation, artificial snow production, etc.) without re-introducing them into the river.

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